Canadian Lobster Atlantic Wide Studies (CLAWS) Symposium: Abstracts and Proceedings Summary

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ABSTRACT

Tremblay, M.J., and B. Sainte-Marie. (eds). 2001. Canadian Lobster Atlantic Wide Studies (CLAWS) Symposium: Abstracts and Proceedings Summary. Can. Tech. Rep. Fish. Aquat. Sci.

A symposium on lobster research conducted under the umbrella of Canadian Lobster Atlantic Wide Studies (CLAWS) was held in Moncton, N.B. from March 28-30, 2000. CLAWS is a multidisciplinary effort directed at understanding lobster production in the Canadian Atlantic. The objectives of the Moncton Symposium were to discuss recent and ongoing lobster research, to receive feedback from stakeholders, and to plan new research under CLAWS II. Participants at the Symposium included representatives from industry, universities and Fisheries and Oceans Science. The Symposium was structured around five Science sessions on days 1 and 2: Larval drift, Juvenile lobsters, Catchability, Assessment Parameters, Fishermen and Science, and a general Poster session. On day 3 (Industry Day) overviews of each session were followed by general discussion. The final session of the Symposium discussed the research planned for CLAWS II.

ACKNOWLEDGEMENTS.

The symposium steering committee included Howard Powles, Michael Chadwick, Gerry Ennis, Louise Gendron, Peter Lawton, Bob Miller, John Moores, Patrick Ouellet, Doug Pezzack and John Tremblay. Logistical arrangements for the Moncton Symposium were made by Michael Chadwick, Marc Lanteigne and Louise Robichaud. Robert Rangeley organized the poster session. The editors thank Howard Powles, Michael Chadwick and John Moores for reviewing some of the contributions. John Moores is thanked for logistical help with translations and printing. All the industry representatives are thanked for putting forward their views at the Symposium.

PREFACE

This report documents the proceedings of a symposium to present and discuss lobster research conducted under the umbrella of CLAWS (Canadian Lobster Atlantic Wide Studies), and to plan research for CLAWS II. The Symposium took place at the Delta Beausejour in Moncton, New Brunswick from March 28-30, 2000.

Representatives of the fishing industry and First Nations from across Atlantic Canada were invited to participate and about 100 people attended part or all of the symposium. John Davis, Assistant Deputy Minister of Science, supported CLAWS by participating in the symposium. Michael Chadwick delivered the opening address on his behalf, noting the importance of lobster in Atlantic Canada, the collaborative nature of CLAWS, and the challenges for a sustainable fishery.

The CLAWS projects were developed at a series of workshops in 1995-96 and 4-year funding was received through DFO's strategic research fund. The CLAWS program was in response to a 1995 Fisheries Resource Conservation Council (FRCC) report on lobster conservation. The FRCC reported "we are taking too much, and leaving too little". Conservation efforts for the lobster resource faced a paradox. For decades scientific analyses had indicated that lobster were fished at unsustainable levels, with estimated fishing mortalities high and minimum legal sizes low relative to the size at maturity and the size of maximum yield per recruit. Despite this, Atlantic lobster landings rose through the 1980s reaching 100-year highs in some areas. This apparent paradox continues to challenge science, since there is currently no clear explanation for the rise in landings other than that environmental conditions were particularly favorable for lobster production in the 1980s.

CLAWS participants included biologists, oceanographers, modellers, geologists, stakeholders and social scientists. They came from DFO Science labs in Quebec and Atlantic Canada, from universities, and from industry organizations. Specific objectives of CLAWS were to develop more accurate and reliable tools for describing lobster stock status; to more clearly describe spatial variability of lobster production; to improve understanding of critical processes underlying lobster production, in particular larval drift and pre-recruit dynamics; to forecast and assess effects of management measures and to communicate results objectively to fishermen and managers.

The Symposium addressed these objectives during five sessions on days 1 and 2 (Larval drift, Juvenile lobsters, Catchability, Assessment Parameters, Fishermen and Science). A general poster session was also held. Day 3 was an Industry Day where Session Chairs provided overviews of their session and then opened the floor for discussion and comment. This was followed by discussion of future funding for lobster research (CLAWS II). Stakeholder representatives were generous with their feedback, both positive and negative. The project work presented at the Symposium represents good progress towards the CLAWS objectives, but much remains to be learned about lobster populations and their response to fishing.

Howard Powles and John Tremblay

SESSION 1: LARVAL DRIFT

Patrick Ouellet

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The Larval Drift component of CLAWS was to address the specific issue of using circulation models to assess the retention capability and/or lobster larvae exchanges among regions. Two distinct projects were carried out on this issue: (1) A study aimed at resolving the ambiguities around recruitment processes off SW Nova Scotia; i.e., the question of interrelations between offshore larval production areas (Georges, Browns Banks) and the prolific fishing ground of coastal SW Nova Scotia. (2) The second study was to address the question that lobster near Magdalen Islands form a closed (self sustained) population; relative to the other proposed Lobster Production Areas (LPA) in the southern Gulf of St. Lawrence. That is, what is the role of currents and what is the degree of larvae retention around the Islands. The research strategy was to be the same for either project: lobster larval transport and exchanges were to be simulated using a combination of oceanographic drift models and information on larvae sources, distribution, movement, duration of stages, etc.

The first contribution to the session was a correlation study revealing the relationship between late-stage lobster larvae abundance and fisheries yield at sites on Nova Scotia coast. Then, four papers presented the results of the larval drift projects off SW Nova Scotia. The first paper dealt with the definition of a lipid-base condition index for lobster larvae. That study showed that stage III and IV lobsters were in better condition off Georges Bank, i.e. off the hatching grounds. The better condition of late larval stages off the banks suggests a mechanism favorable to survival during dispersal over the deep waters of the Gulf of Maine. The next three papers presented the model and larvae tracking experiments off SW Nova Scotia. First, the distributions of the various larval stages were investigated to provide necessary information about hatch sites and larvae distribution for the modelling effort. Drift pathways are strongly dependent on the larvae vertical distribution and the location of the hatching sites. The results of simulations reveal limited larval drift into the inshore zone in the vicinity of Lobster Bay, because of the existence of convergence at the tidal-mixing front over Lurcher Shoals. In addition, few, if any, of the modelled larvae were transported from Georges Bank towards SW Nova Scotia.

The last two papers report on the Magdalen Islands larval drift simulation project. A high spatial resolution, 3-dimentional, circulation model, was produced for the area around the Magdalen Islands. Simulations of the dispersal of early larvae stages confirmed that wind driven circulation and larval drift patterns can be responsible for large inter-annual variability in larvae and post-larvae abundance, hence on settlement success, around the Magdalen Islands.

DEVELOPMENT OF A LARVAL LOBSTER CONDITION INDEX AND LARVAL DISTRIBUTION AND VIABILITY IN THE GEORGES BANK REGION.

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The triacylglycerol/sterol condition index was applied to larval lobster populations in the vicinity of Georges Bank in the Gulf of Maine. This index is related to larval size by an increasing power function which explains around 40% of the variation. This poor fit can be explained by the uneven increase in triacylglycerol levels during development within each moult stage. Increased pigmentation is not related to larval condition, as measured by lipid storage, and masks the increased yellowish hue of lipids as development proceeds. The larval triacylglycerol/sterol index appears to undergo a diurnal cycle in stage III and IV lobsters, with lowest values at midday and highest values after dark. This pattern can not be explained by nocturnal feeding which leaves the possibilities that satiated larvae descend below the surface metre during daylight and are therefore underrepresented in our collections by being more vertically diffuse and/or healthy well-fed larvae would be more likely to detect the trawl and escape during daylight. Few stage I and II lobster larvae were found in the vicinity of Georges Bank with a condition index less than 0.1, which is the level laboratory studies indicate approaches the “point-of-no-return”.

The condition of all developmental stages was found to be better in individuals located off Georges Bank. This is not ecologically significant in the case of the first two stages because such a small proportion of the population was actually located off the bank. It is not resolved how the third and fourth stages arrive off Georges Bank, since shoal water hatching is the norm, but their lipid reserves are significantly greater than identical developmental stages on the bank. Finally, the density of stage IVs in the adjacent surface waters over the Gulf of Maine was twice that found over Georges Bank. This suggests that the lobster has evolved a life cycle in offshore waters in which larvae are hatched in shoal waters over the banks but the last two planktonic/pelagic stages either seek or are transported to, and by stage IV thrive in, the warmer stratified layer over the deeper waters of the Gulf of Maine.

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LARVAL LOBSTER DISTRIBUTION, VIABILITY AND DISPERSAL IN THE BROWNS – GERMAN BANKS AND COASTAL SOUTHWEST NOVA SCOTIA REGION: (1) LARVAL DISTRIBUTION AND ECOLOGY

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This project is linked with those described in Drinkwater et al. and Hannah et al. (this symposium). The purpose behind these projects is to resolve the ambiguities around lobster recruitment processes off SW Nova Scotia by modelling larval dispersal from known inshore and offshore spawning areas. Two large-scale lobster larval surveys conducted out of St. Andrews in the 1970s (Stasko and Gordon 1983) and our own larval studies near Browns and Georges Banks done in the 1980s (Harding et al. 1999) provide some of the basic observational information needed to model larval drift in the area. Unfortunately, the St. Andrews surveys were undertaken with near surface tows before it was appreciated that the earlier larval stages could undergo considerable vertical migrations daily.

Presented here are the results from three years of field work supported by CLAWS 1, spread between inshore and offshore locations, and one year of larval drift modelling. In this paper we present information gained on spawning locations, particularly in inshore areas, and the vertical distribution of the larvae, together with observations on the condition of settling stage lobster (Stage IV). In August of 1996 the MV Navicula was used to sample inshore waters from Cape Fourchu to Cape Sable during two weeks in August with a Vass-Tucker trawl. First stage lobsters were abundant as expected but the later developmental stages were almost absent with only three stage IV lobster larvae captured off Cape Fourchu. This differs markedly from work in the 1970s when the settling stage larvae dominated the catch (Stasko and Gordon 1983). We have no explanation for this observation since our sampling covered much of the same inshore area as the earlier study. Horizontal towing at different depths was done to obtain a picture of vertical distribution of stage I larvae. The sampling site at the mouth of Pubnico Harbour coincided with active larval releases, judging from the predominance of intramoult stages A & B. Stage I lobster were mainly distributed in subsurface waters both day and night, which explains their absence from the surface tows of previous studies. The three stage IV lobsters caught were in good condition, judging from their triacylglycerol/sterol ratio, which makes it even more puzzling why there were so few in inshore waters this year.

In August of 1997 we concentrated our efforts on tracking larval drift from a transect off Browns Bank into the NE Channel, NW of Browns Bank and along a transect from German Bank into the Gulf of Maine. Stage I larvae were widely distributed and often found off the banks but in near proximity to them. Stage IV lobsters appeared to be located from the NW tip of Browns to the Gulf side of German Bank. The condition of Stage IV lobster near Browns Bank was significantly better than specimens collected in open waters of the Gulf of Maine. A transect was run off German Bank into the middle of the Gulf of Maine to corroborate previous occurrences of stage IV lobster towards the centre of the Gulf Maine. High abundances were confirmed in the centre of the Gulf near the international boundary.

In August of 1998 we directed our efforts approximately equally between 1) describing the vertical distribution of the lobster larvae in both inshore and offshore locations and 2) tracking larval drift from the NW tip of Browns Bank and from the approaches to Lobster Bay. Again, only first stage larvae were abundant inshore and these were distributed evenly throughout the entire water column of 30m depth both day and night. There was no evidence for a nocturnal migration to the surface as previously described for Browns Bank (Harding et al. 1987). The water column was cold, 7 to 9 °C and isothermal, and tidal turbulence could have disrupted any synchronized migratory activity. At the offshore location off German Bank the population was predominantly composed of settling stage (IV) lobster. They were distributed above the thermocline (7.5m depth) with most individuals captured in the top metre. When these results were plotted on a 24-hour scale, a clear pattern of near dawn and near dusk appearance in the surface tows occurred. There were significantly more larvae captured in the surface waters near dawn and dusk than during the day and night, which is commonly known as a twilight vertical migration. The condition of stage IVs in the frontal zone off German Bank was comparable to those captured elsewhere that year. The larval size, however, was small. Stage IV lobster larvae from the German frontal zone were smaller than those from Georges Bank and considerably smaller than those from Browns Bank collected in previous studies. This characteristic is highly dependent on thermal history of the individual and may serve to identify larval origins and thus deserves more attention.

In conclusion, settling stage lobsters were noticeably absent from waters inshore of the German Bank frontal zone in all three years. Interpretation of earlier work suggests that in 1977 and 1978 stage IV had a continuous distribution from the offshore to the inshore in a narrow corridor at Cape Sable on the east and west of Cape Fourchu on the west. For modelling purposes, Lobster Bay is a prolific source of hatching larvae, which reside throughout the water column in this very turbulent environment. The later development stages are more commonly found in the offshore where they frequent the warm surface layer. Stage I and II larvae undergo an extensive daily vertical migration within the upper mixed layer. Stage IV are distributed very close to the sea surface in the absence of bright sunlight and appear to undergo a small-scale twilight migration, which explains our previous observations of their absence from the surface waters of the Gulf of Maine in bright sunlight.

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LARVAL LOBSTER DISTRIBUTION, VIABILITY AND DISPERSAL IN THE BROWNS-GERMAN BANKS AND COASTAL SOUTHWEST NOVA SCOTIA REGION: (2) RESULTS OF LOBSTER LARVAE TRACKING PROGRAM

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As part of the CLAWS I observational and modelling study of lobster larval drift off southwestern Nova Scotia, larval surveys were conducted in the summers of 1997 and 1998 in the vicinity of Browns and German Banks. Satellite-tracked drifting buoys were released during these surveys in regions of high larval abundance or expected lobster spawning sites and were followed for periods from a day to over a week in an attempt to determine the most likely drift paths of the larvae. In addition, around the clock larval sampling was carried out at each drifter. These drift measurements provided direct current information, but unfortunately were rather limited in their temporal and spatial resolution. Indeed, their primary purpose was to evaluate the usefulness of a numerical model for predicting drift tracks of the larvae.

In 1997, 4 GPS drifters with a 10-m drogue attached just below the buoy were released near the southwestern edge of Browns Bank. Hourly values of their positions were relayed via the ARGOS satellite. Strong northwesterly winds a day after their release pushed three of the four buoys into Northeast Channel. These three buoys were retrieved and redeployed immediately to the north of Browns Bank. A second redeployment took place 2 days later in approximately the same region. These were tracked for an additional 1 to 2 days, retrieved and then deployed in the vicinity of German Bank.

In 1998, a total of eight drift buoys drogued in the top 10 m were released on and around the southwestern edge of Browns Bank and tracked for about a week. One of the buoys was lost on the fifth day of tracking. The remaining buoys were retrieved, redeployed inshore of German Bank and tracked for approximately 4 days.

The drifters revealed several previously observed circulation features, including clockwise circulation around the cap of Browns Bank, a tendency towards flow off Browns Bank to the north, weak eastward flow between the Bank and Lurcher Shoals, offshore flow off southwest Nova Scotia, clockwise circulation on German Bank and northward flow on the outer edge of Lurcher Shoal.

Currents and drift tracks derived from the buoys were compared with those generated by the numerical model by two separate methods. First, we removed the tidal signal from the velocities estimated from the drift buoy positions through filtering and then averaged the resultant velocities over a 24-hour period to obtain daily mean currents. These were assigned to the mean position of the buoy for the day in question. Visual comparison of these velocity vectors with those generated by the model using the climatological density fields and mean summer winds showed relatively good correspondence. An exception was the southwestward flow off Browns Bank into Northeast Channel during a storm.

In addition, particles were released in the model at equivalent locations to the release points of the drift buoys and at equivalent stages of the tide. The model runs used the climatological winds and density fields. Drift tracks from the buoys and the model again show similar behaviour. This was particularly true for the area between Browns Bank and Lurcher Shoals, a region of weak currents. There was also good agreement between model and observations on Lurcher Shoals and on German Bank. On the latter the buoy and the model particle remained on the Bank for the entire 4 days of tracking. The largest discrepancy between the observed and the predicted flows from the climatological model runs occurred during the initial deployment in 1997 when strong north to northwesterly winds blew the drift buoys into Northeast Channel. The climatological model predicted that the buoys would have moved northwestward along the edge of Browns Bank. This large difference is not surprising given that the strength of the peak winds during this deployment was around 15 ms^{-1}. Rerunning the model using the observed mean daily winds during the storm produced a much closer correspondence between the buoy tracks and the model predictions for 3 out of the 4 buoys. The other main discrepancy between buoy and modelled tracks was to the west of German Bank where the observed velocities were consistently larger than the model predictions. This was not due to the differences between the climatological winds used in the model and the observed winds.

Data on the concentration of lobster larvae by stage in the vicinity of the buoys while they drifted indicated no significant import or export of larvae during the tracking experiments. This suggests that the buoys were tracking lobster larval drift.

In conclusion, the numerical circulation model used in our study was able to recreate most of the major features in the summertime flow fields revealed by the drift buoys. While simulations are improved with the inclusion of the observed winds during the buoy deployments, the climatological current fields generated by the model capture most of the observed current structure.

LARVAL LOBSTER DISTRIBUTION, VIABILITY AND DISPERSAL IN THE BROWNS-GERMAN BANKS AND COASTAL SOUTHWEST NOVA SCOTIA REGION: (3) MODELLING THE DRIFT OF LOBSTER LARVAE

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As part of CLAWS I (Canadian Lobster Atlantic Wide Study), we undertook a project to determine if larvae from the offshore hatching grounds around Georges, Browns or German Bank were the source of the high recruitment to inshore regions off southwestern Nova Scotia. To achieve this objective, a combination of field and modelling studies were pursued. This presentation discusses initial modelling results.

Three-dimensional summer flow fields were derived from finite-element numerical models of the Scotian Shelf and Gulf of Maine (Lynch et al. 1996; Hannah et al. 2000). As part of the CLAWS project, the model was modified to include more realistic physics in the very near surface layer (upper few meters) because of the potential importance of drift of lobster larvae within this layer. The model includes a climatological wind-driven Ekman layer in the upper 5-m overlying flows driven by tides and the pressure gradients associated with density and wind forcing. It reproduced the main observed circulation features (Hannah et al. 2001) and matched closely the currents observed from the tracking of drift buoys.

To determine if Georges, Browns, or German Banks were possible sources of larvae to the region off southwest Nova Scotia, particles were released in the model flow field at specified depths from each of these banks and advected for durations of up to 60 days. Particles were also released in the Lobster Bay area. They were tracked using the model currents averaged over the top meter, averaged over the top 5 m, and at 10 m. The number of particles located in the inshore, midshore or offshore regions off southwest Nova Scotia, on Georges Bank or in the Bay of Fundy-coastal Maine region (see Fig. 1 for area definitions) after 30 days as a function of release site was calculated. Particles reaching the model shoreline (<20 m depth) were considered trapped in the inshore area and not tracked any farther. The climatological circulation field, based upon the summertime means of both the density field and winds and M_2 tidal forcing, were initially used.

Particles released on the north flank of Georges Bank within the top meter flowed eastward, being entrained into the well-known Georges Bank anticyclonic gyre. After rounding the eastern tip of Georges Bank the flow divides near the southeastern edge of the Bank, with some particles moving offshore and eastward while the remaining particles flow southwestward along the edge of the continental shelf. A similar pattern emerges for the 0-5 m layer but with a greater percentage of the particles flowing southwestward. This contrasts with the particles at 10 m where the majority of particles are caught within the anticyclonic gyre and few particles move offshore. For particles released within the top 1 m or 5 m, most were either transported off the shelf into the slope water region or advected southwestward towards the Middle Atlantic Bight. Three percent of the particles in the top meter remained on Georges while approximately 19%

did so in the top 5 m (Fig. 2). At 10 m, over 80% of the particles remained on the Bank with less than 1% reaching the midshore region off southwest Nova Scotia.

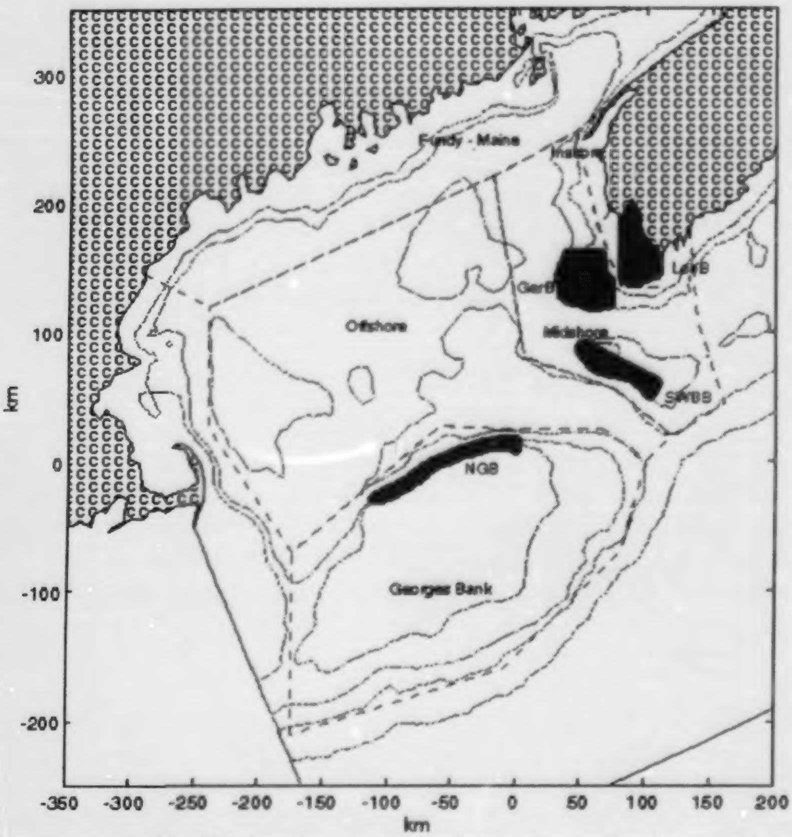

Fig. 1. Gulf of Maine showing the release sites and subareas for particle counting of end positions of modelled lobster larvae drift after 30 days.

Particles released within the top meter and top 5 m on the southwestern edge of Browns Bank were transported eastward, most off the Bank, in response to the mean southwesterly winds. In contrast, at 10 m, the primary movement was to the north to northwest. Most of the particles continued on a northward path, remaining just offshore of the 100 m isobath of Lurcher Shoals. After 30 days the leading edge of the particles had reached the mouth of the Bay of Fundy and by 60 days many particles were headed southwestward, caught within the Maine Coastal Current system. Again, most of the particles released in the top meter and top 5 m were swept off the shelf and out into the slope water after 30 days. Less than 2% of the particles in the top meter were located in the midshore region and 11% of those in the top 5 m (Fig. 2). In contrast, almost 70% of the particles at 10 m were located in the midshore region. Just over 1% of the particles made it to the Bay of Fundy/Coastal Maine region and the remainder were advected to locations outside of our main area of interest.

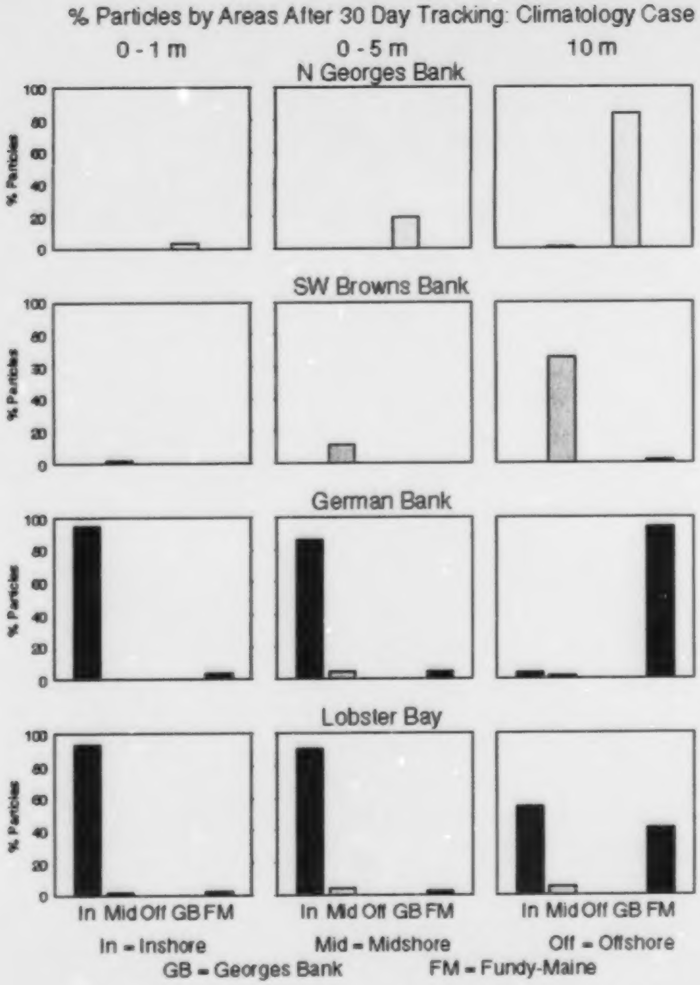

Fig. 2. The number of particles expressed as a percentage of the total released that are within a given subarea after 30 days of drift as a function of release site (rows) and depth (columns). The subarea names are given at the bottom of the figures and their geographic boundaries are shown in Fig. 1.

On German Bank, the predominantly northward flow towards the Bay of Fundy carries particles in the top meter and top 5 m to the vicinity of Cape St. Marys. At 10 m, most particles move northward eventually flowing into and around the outer Bay of Fundy and then southwestward off the coast of Maine. Approximately 95% of the particles released in the top meter and 85% in the top 5 m from German Bank were in the inshore region after 30 days (Fig. 2). These were all located in St. Marys Bay while none were transported into Lobster Bay. A small percentage in both layers remained in the midshore region and some made it to the Fundy/Maine region. In contrast, 94% of the 10 m releases were transported into the Fundy/Maine region and only a small percent made it to the inshore (4%) or offshore (<1%) regions or remained in the midshore region (<2%).

From Lobster Bay, particles in the top meter or top 5 m move offshore out across Lurcher Shoals, then northward to the Bay of Fundy with many coming ashore around Cape St. Marys. The particle positions also reveal that many go ashore within Lobster Bay. A small percentage of the particles are transported south and then eastward to the Scotian Shelf. At 10 m, there are also significant numbers that both remain within Lobster Bay and reach Cape St. Marys, but many that make it into the Bay of Fundy and then southwestward along the coast of Maine. Although a few particles move south of Lobster Bay to a position near the 100 m isobath, none are advected towards the Scotian Shelf. At all three depths, the majority of the particles from Lobster Bay remain in the inshore region after 30 days, over 90% in both the top meter and top 5 m and approximately 54% at 10 m (Fig. 2). Thirty to 35 percent remain within the Lobster Bay region (extending from Cape Sable to just north of Lobster Bay proper) and around 60% are advected to the region between Cape St. Marys and Yarmouth. Fewer than 2% and 4% in the top meter and top 5 m, respectively, are located within the midshore and approximately 2% in the Fundy/Maine regions. At 10 m, 5% of the particles are located in the midshore region after 30 days and over 40% reach the Fundy/Maine region. It should be noted that the case of the Lobster Bay releases are considered less realistic than the others because of limited model resolution compared to the size of the Bay and particles not being advected once they reach the model coastline.

The model was also used to examine the sensitivity to varying wind direction. Wind stresses with magnitudes twice that of the mean and from each of the eight quadrants were used to force the circulation model. The resultant currents were then used to transport the particles released at each of our four sites for up to 60 days. As expected, particles in the Ekman layer (top meter and top 5 m) show varying responses depending upon wind direction. The response in these upper layers is typically to the right. Below the Ekman layer (10 m), there are much smaller differences in the responses. There are indications of particle exchange among many of the offshore (> 50 m isobath) release sites (e.g. Browns, German and Georges Bank) but only for a limited range of wind directions in some cases and hence of low probability.

The model suggests limited drift into the inshore (< 50 m) zone in the vicinity of Lobster Bay off southwest Nova Scotia. This is in large part because of the existence of convergence at a tidal-mixing front on Lurcher Shoal running parallel to the coast and located over approximately the 75 m isobath. These results suggest that the most likely source of lobster larvae for the inshore area of Lobster Bay is local production or from regions not investigated with the model. For the inshore area around St. Mary's Bay, particle modelling suggests larvae can come from Lobster Bay, German Bank, or perhaps Browns Bank. In the midshore region, the primary sources of the sites investigated are German and Browns Banks. Few, if any, of the model particles are transported from Georges Bank towards southwest Nova Scotia.

Our conclusions on lobster larval drift from model simulations must be viewed with caution. They are based upon drift at a particular depth or within a given depth level, and hence ignore larval behaviour such as daily vertical migration, depth-dependent stages or swimming (Harding et al. 2000). In addition, we neglect upwelling and downwelling of the water column that could move larvae vertically and eddy variability such as that seen on northern Georges Bank and along the Lurcher Shoals front that could move them horizontally. Full temporal variability in the wind forcing, including diurnal sea breezes in the coastal area (e.g. Incze et al. 2000), has not yet been included. Also, our conclusions are based primarily upon a drift duration of 28-30 days. This is less than the expected larval duration (hatching to half way into stage four when they are expected to settle). Still our modelling studies do suggest that few if any larvae are advected into Lobster Bay and adjacent inshore areas if hatched on Georges, Browns or German Bank. This together with the result that upwards of 30-35% of the larvae produced in Lobster Bay would remain there after 30 days leads us to the preliminary conclusion that local production is the likely source of lobster larvae in Lobster Bay.

Future work under the CLAWS II program will focus upon incorporating temperature-dependent stage durations for the lobster larvae, stage-dependent depths, time varying winds for all years where possible and exploring the possibility of directional swimming by the larvae. In addition, we will improve the resolution of the circulation model in and around Lobster Bay.

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MODELLING CIRCULATION AND LOBSTER LARVAE DISTRIBUTION AND DISPERSAL AROUND MAGDALEN ISLANDS

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The study was carried out in two steps. The first was to deploy surface drifters and current meters in the area and to use the collected data to validate the wind-driven part of a full three-dimensional circulation model. The measurements of currents were realised in July 1998. The model used is one initially developed by Backhaus (1983), and modified by Stronach (1993) and by Saucier et al. (1997, 1999) and Saucier et Chassé (in press). The model runs and the calibration were completed in 1999.

The second step was to use this validated model with the observed winds in July of 1996 and 1997 to reproduce the drift of emerging lobster larvae. These modelled drifts were used to produce relative larvae concentrations that we compare to the actual weekly observations. The wind regime in July 1996 was quite different from the one in July 1997. The observed larvae concentrations were also quite different between those years. More intense winds in 1996 than in 1997 induced larger drifts, and a lower concentration of larvae was observed in 1996. The model reproduced these differences. We will now compare the model results with the observed larval concentrations in 1998.

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LOBSTER (*HOMARUS AMERICANUS*) LARVAE ABUNDANCE AND POST-LARVAE AVAILABILITY TO SETTLEMENT AT THE MAGDALEN ISLANDS, SOUTHERN GULF OF ST. LAWRENCE (QUEBEC)

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Introduction

Lobster populations in coastal areas of the Gulf of St. Lawrence are to some degree most likely linked through larval exchanges or benthic juvenile and/or adult displacement. However, fisheries managers recognize numerous small adjacent fishing zones for lobster exploitation which may or may not correspond to independent (i.e., self-sustaining) biological units. Recently, it was proposed to create larger managerial units called 'Lobster Production Areas – LPAs' that would incorporate the existing fishing zones and where lobster population dynamics should be homogenous (FRCC 1995). One proposed LPA is the area around the Magdalen Islands in the southern Gulf of St. Lawrence where earlier studies suggested that local lobsters form one self sustaining population (Dubé and Grondin 1985).

In 1995, a research program on lobster biology, ecology and fisheries was initiated by the Department of Fisheries and Oceans (Canada). Among the projects included in the program was an initiative to use a sophisticated 3D-circualtion model of the Magdalen Islands region to interpret larvae distribution and to identify transport/retention mechanisms. The objectives were (1) to look at relationships between local larvae (planktonic stages: zoea-I to zoea-III) production and post-larvae abundance, and (2) to determine the role of hydrodynamic processes in controlling post-larvae availability and settlement success.

Surveys of larval lobster abundance and horizontal and vertical distributions were conducted for three years near the Magdalen Islands. The information was then used with a model of the surface circulation to simulate larval drift and to determine the role of physical factors in controlling the availability of post-larvae lobsters to bottom settlement.

Methods

First, large-scale surveys were carried out in July of each year from 1996 to 1998 (Table 1). Two $1m^2$ square (1m × 1m) nets mounted on top of each other (i.e., sampling between 0 to 1m and between 1 to 2m simultaneously) were fixed below the mid section of the bow bridge of a SWATH (Small Waterplane Area Twin Hull) ship: the F. G. CREED. This system allowed sampling of the undisturbed first two meters of the water column with great efficiency.

Table 1. Sampling schedule at the Magdalen Islands for the period from 1996 to 1998.

Year	Cruise	Date	Tow type	Day	Night
1996	CREED	13 – 21 July	Neuston/surface (0 – 2 m)	23	17
	BW	28 June – 11 Sept.	Neuston/surface (0 – 0.5 m)	192	
1997	NAVICULA	2 – 23 July	Neuston/surface (0 – 1 m)	54	25
			Deep (5 to 25 m)	37	20
	CREED	1 – 12 August	Neuston/surface (0 – 2 m)	46	
	BW	22 July – 4 Sept.	Neuston/surface (0 – 0.5 m)	58	
1998	CREED	11 – 22 July	Neuston/surface (0 – 2 m)	61	
	BW	6 July – 11 Sept.	Neuston/surface (0 – 0.5 m)	150	

BW = "Boston Whaler" type (8 m) vessel

In addition to the July surveys, each year, from the last week of July to the second week of September, sampling was conducted in the southeast sector (Baie de Plaisance) to investigate the distribution and to quantify lobster post-larvae abundance (Table 1, Figure 1). Two rectangular nets (1m × 0.5m) attached side by side (i.e., for a 2m × 0.5m or $1m^2$ total opening area) were mounted on an articulated aluminium arm at the bow of a small Boston Whaler type vessel. Daily sampling was carried out when possible given the meteorological conditions, usually 3 to 4 times a week, during the entire period.

The comparison of larval stage abundance between seasons and/or years and computation of seasonal larvae production are based on the weekly mean abundance of the various larval stages. Larval production for each stage was computed by integration of the area under curves of weekly mean abundance (Incze et al. 1997).

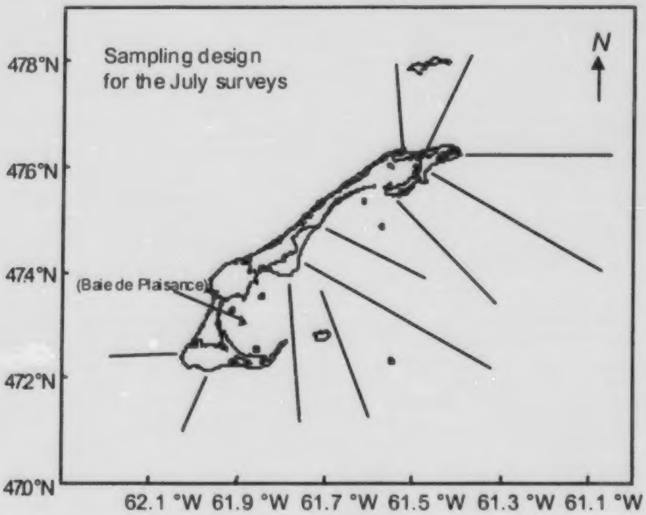

Figure 1. Distribution of the sampling lines and the fixed stations for the July surveys of lobster larvae distribution for 1996 to 1998.

Results

Lobster larvae and post-larvae production

Zoea I larvae appeared around the Islands at the end of June – early July and mean concentrations peaked in the second and third week of July in 1996 and 1997, respectively. Zoea-I production lasted until the end of August – early September in the southeast sector but weekly mean larvae concentrations were always lower than those recorded earlier in the northeast sector (Table 2). In 1998, the sampling season started later and we may have missed the maximum of larval release in early July. However, the production of zoea-I larvae in the southeast sector for the second part of the season was the lowest of the three years (Table 2).

Table 2. Estimated seasonal production of lobster zoea-I larvae from integrated plot of weekly mean abundance. *In 1998, sampling began on July 13; week #3. ** For southeast sector (Baie de Plaisance) only.

Period	Year		
	1996	1997	1998*
July	42.3×10^3 km^{-2}	51.9×10^3 km^{-2}	28.9×10^3 km^{-2}
**August-Sept.	32.4×10^3 km^{-2}	39.8×10^3 km^{-2}	14.1×10^3 km^{-2}
Total	74.7×10^3 km^{-2}	91.7×10^3 km^{-2}	43.0×10^3 km^{-2}

There was also an important difference in the production of zoea-II larvae among years. In July 1996, the production of zoea-II larvae was estimated at 3.41×10^3 km^{-2} or 8% of the zoea-I production while, for the same period in 1997, zoea-II production was estimated at 14.0×10^3 km^{-2} or 27% of the zoea-I production. The same pattern was observed for the second sampling period when, for the southeast sector, zoea-II larvae represented 6% of the zoea-I produced in 1996 compared to ca. 15% in 1997. In 1998, for the southeast sector, zoea-II larvae production in August was again very low at ~2% of the estimated zoea-I larvae production. These differences have an effect on the seasonal production of lobster post-larvae in the southeast sector (Table 3).

Table 3. Estimated seasonal production of lobster post-larvae in the southeast sector.

Period	Year		
	1996	1997	1998
August/Sept.	1.28×10^3 km^{-2}	4.62×10^3 km^{-2}	1.78×10^3 km^{-2}

The inter-annual difference in abundance of lobster post-larvae was apparently reflected in the abundance of lobster early benthic stages in Baie de Plaisance. The density of juvenile lobsters was higher in 1997 relative to 1998 and 1996 (Sainte-Marie et al.– this symposium).

The physical environment

Each year, the maximum surface temperature (hence, the minimum time between moults) was reached in the first week of August (Figure 2). From the end of June to early August, the seasonal changes in water temperature were similar between 1996 and 1997, with rates of increase at 0.16°C and 0.12°C day^{-1}, respectively. In comparison, in 1998 water temperature was high already in July (Figure 2). After the early August maximum (highest in 1996), the water temperature began to decrease in 1996 and 1998 at -0.03 and -0.05°C day^{-1}, respectively, while temperature remained high and more stable until early September in 1997.

However, the important difference between the 1996 and 1997 seasons were in the wind pattern observed and its effect on water circulation and larval drift. For the first half of July in 1996, the surface circulation conditions were not favourable to zoea-I retention near the Islands (Lefaivre et al.- this symposium). In contrast, retention of zoea-I larvae was high in early July 1997, a situation that can explain the abundance of stage II and III larvae in 1997 in comparison to 1996. In addition, the low abundance of post-larvae and low recruitment to the bottom in 1996 may be the result of important lobster larvae advection from the region in August 1996. Larval drift simulations for the 1998 season are not available at the moment.

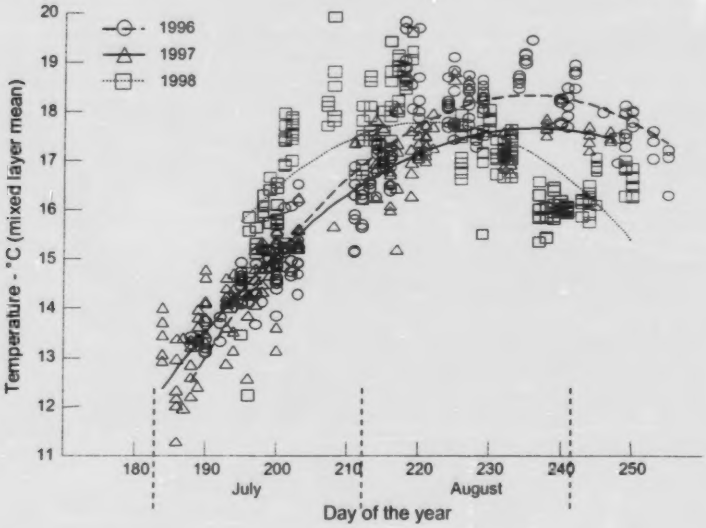

Figure 2. Daily mean water temperature for each sampling season.

Discussion

Assuming no change in the reproductive potential of the adult lobster population during the period of study; 1996 to 1998, we have shown that the local circulation conditions can have a determinant role in the retention or dispersion of lobster planktonic stages around the Magdalen Islands. Although still in development, the strategy of using a circulation model to simulate planktonic lobster distribution around the Magdalen Islands shows the potential importance of physical forcing in determining recruitment, i.e., post-larvae abundance. However, the physical forces can only act on what is present in the water and larval emergence pattern, total production (i.e., the population reproductive potential), larvae development and growth (i.e., water temperature regime) and behaviour (i.e., vertical distribution) in combination with the hydrodynamics of the region will create the potential for lobster year-classes success or failure.

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SESSION 2: JUVENILES

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The Juveniles component of CLAWS sought to advance understanding of the factors responsible for the expression of year-class strength in lobsters. Though not yet realised, development of a recruitment forecasting capability is a longer-term objective of this research.

The first paper presented an integrative approach to describing the composition, size and spatial pattern of substrates used as sheltering habitats by juvenile lobsters. Seabed topography and lobster habitat use was studied using side-scan sonar, video, and direct benthic sampling at study sites in two major lobster production areas. Published equations on minimum shelter size-lobster size relationships were applied to interpreted habitat maps to derive preliminary estimates of the carrying capacity of various habitat types, and to explore potential shelter availability bottlenecks. A second paper developed this spatial analysis approach further, advocating the adoption of landscape ecology approaches in lobster research. Habitat structure was compared across study sites at equivalent spatial scales. Analyses were presented on the linkage between lobster density and the size and fragmentation of habitat patches.

The third paper in the session reviewed several years of intensive field sampling of juvenile lobster populations in the Magdalen Islands. The work focussed on linkages between postlarval abundance, cohort strength at settlement, and the propagation of cohorts through time. Advances in our knowledge on growth of juvenile lobster were realised through this project. The density of settlers, or year-class strength, varied considerably across the years of the study. A subsequent paper, reporting on laboratory rearing studies, investigated how behaviour, growth and survival of recently settled lobsters change in relation to density and shelter availability.

The fifth paper reported on stomach content analysis of juvenile lobsters. There was no evidence of suspension feeding (on planktonic prey), even by the smallest lobsters sampled. Lobsters, irrespective of size, ate the same broad categories of prey. Abundance of rock crab, bivalves and unidentified flesh, the three most important prey items, changed gradually with lobster size. However, taking all food items into account, there were natural breaks in diet that compared well with a recent classification scheme for ontogentic phases in lobster life history.

The final presentation reviewed demersal fish feeding habits in the southern Gulf of St. Lawrence. Extremely low incidences of predation on lobster by Atlantic cod and American plaice, obtained in extensive studies conducted prior to the CLAWS program, were attributed to significant spatial segregation for much of the year between these fish species and lobster. Samples collected during the CLAWS project, though of limited spatial and seasonal coverage, had the advantage of covering eight shallow water species at times of species overlap with lobster. Shorthorn sculpin, cunner, and white hake were all determined to consume juvenile lobster.

Results from the Juveniles component of CLAWS have important implications for future research and fishery management practices. Further quantification of geographic variation in spatial scaling of lobster habitats is necessary; and we should not assume that large areas of shallow coastal substrates are homogeneous in their carrying capacity for juvenile lobsters. There is now more confidence that we can recognise and track early cohorts through time for several years. Although diver-based sampling is labour-intensive, results are sufficiently encouraging to justify further work to explore linkages to fishery-independent prerecruit surveys, and to the occurrence of prerecruits in the commercial trap fishery. Fine behavioural observations of the type gained in the recent laboratory studies may be important for determining seeding densities and optimal design for artificial reefs, and to understand how density-dependent processes operate. Failure to take into account these types of patterns could impact the effectiveness of conservation measures.

SPATIAL SCALING IN COASTAL LANDSCAPE STRUCTURE AND THE DISTRIBUTION OF JUVENILE LOBSTERS

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Juvenile lobsters (*Homarus americanus*) are ecologically distinct from larger individuals for approximately their first three years by adopting a cryptic life style and by being behaviourally restricted to sheltering habitats (Lawton & Lavalli 1995). Suitability of these types of habitats, for benthic animals generally, is thought to depend on the composition, size and spatial pattern of substrates over a range of spatial scales. Understanding spatial patterns of benthic substrate use is critical for predictions of lobster abundance and for identifying processes that influence settlement success and subsequent survival. Ecological processes may influence abundance at several spatial scales. At large scales dispersal of larvae may create large-scale gradients in densities arriving at nursery grounds. Large-scale variation in benthic substrates down to smaller-scale patchiness of habitats, other resources or predators may also create patchiness in local densities (Underwood 1997). In this study we test for spatial-scale variability in juvenile lobster density and in the availability of shelter habitats.

Seabed topography and lobster habitat use was studied using side-scan sonar, remote video and diver operated video and quadrat sampling in two major lobster production areas: Val Comeau, New Brunswick, in the southern Gulf of St. Lawrence, and in Lobster Bay, Nova Scotia, in the Gulf of Maine (Figure 1). The following will focus on results from Val Comeau. Sidescan sonar survey area totalled 7 km^2. Approximately 26 km of remote camera survey tracks and over 9000 m^2 of diver-held video images for analyses of shelter habitats were completed. Over three thousand 0.25 m^2 quadrats (total area = 750 m^2) on 100m transects and 450 quadrats (112.5 m^2) on grids of 6.25 m^2 or 25 m^2 were measured and searched. Sampling was conducted in July so the current year's cohort was not represented (Figure 2). Rock size was used as a proxy for shelter size, as in previous studies. Minimum shelter size-lobster size scaling equations, used here to estimate habitat availability, were empirically derived in laboratory studies by Wahle (1992).

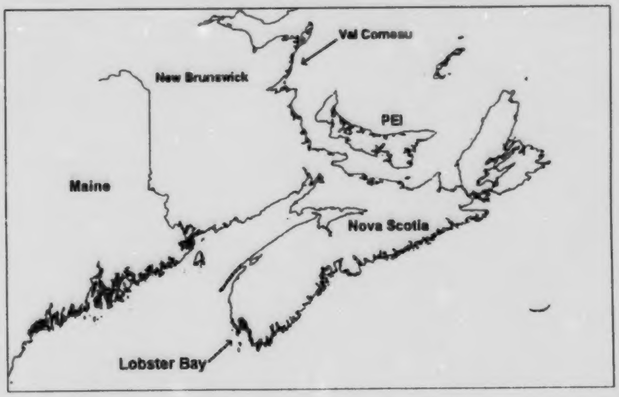

Figure 1: Val Comeau and Lobster Bay study sites.

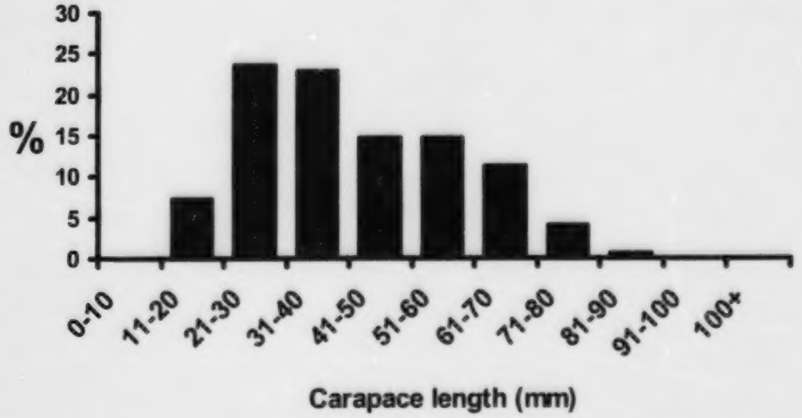

Figure 2. Frequency distribution of lobsters at the Val Comeau site. Samples of the post-settlement (~5-10 mm) size class were not collected.

Large-scale complexity and fragmentation of substrates was clearly evident from side-scan sonar images. These data were ground-truthed using remote video and substrates were then broadly classified into Gravel, Bedrock and Sand. Over 75% (n = 150) of juvenile lobsters (< 50 mm CL) were in the Gravel areas with average densities (0.21 ± 0.9 m^{-2}) significantly higher than in Bedrock (0.09 ± 0.7 m^{-2}) and Sand (0.06 ± 0.5 m^{-2}) (Figure 3). There were no significant differences (ANOVA: F = 0.23, df = 2, 2714, p = 0.79) in densities (n = 37, 0 = 0.04 ± 0.39 m^{-2}) of larger lobsters (> 50 mm CL) among substrate types.

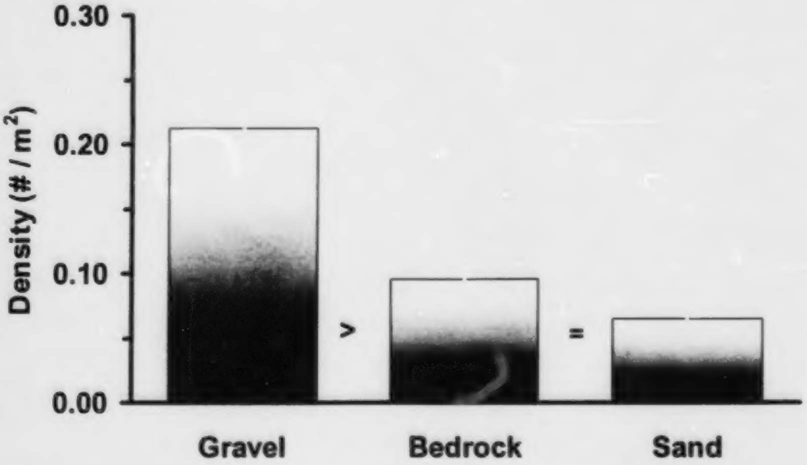

Figure 3: Juvenile lobster densities were highest in Gravel substrates (F = 8.04, df = 2, 2714, p < 0.001) consisting of cobble and boulder size rocks.

Small-scale patterns in shelter size distributions were analysed in one of the large Gravel areas (0.37 km^2) where lobster densities were highest ($0 = 0.56 \pm 0.55\ m^{-2}$). All rocks ($n = 28293$) in the 450 quadrats were measured from videotaped images. The area was characterised by a high fragmentation (fractal) exponent indicating a large number of available small shelters relative to larger ones. High fragmentation of the habitat into pebble and small cobble-sized rocks created a high number and high density of shelters suitable for the smallest size classes of lobsters. However, grids with a lower level of fragmentation (0 exponent = 1.65 ± 0.22) supported higher densities ($0 = 1.28 \pm 0.55\ m^{-2}$) of all size classes compared with those that were more fragmented (0 exponent = 1.86 ± 0.15; 0 number of lobsters = $0.25 \pm 0.18\ m^{-2}$). This pattern was further supported by a significant positive relationship between area cover of large cobbles and boulders and juvenile lobster density ($r^2 = 0.68$, $p < 0.001$).

At larger scales (km^2) there were spatial differences in habitat availability that explained a significant amount of the variation in lobster densities. Juvenile lobsters occurred only on substrate patches with cobbles and boulders and the size of occupied patches was greater than patches without lobsters (mean diameter 45.7 vs. 22.8 m). Within occupied patches, lobster densities increased with increasing area cover of cobbles and boulders ($F = 3.62$, $df = 2,46$, $p = 0.035$). There were no differences in lobster densities on patches with or without kelp present ($F = 0.87$, $df = 47$, $p = 0.355$).

Potential carrying capacity among substrate types and locations suggested habitat limitation may occur at low densities. In the Gravel areas with the greatest area cover of cobbles and boulders, there was an exponential decline in shelter availability with increasing body size. Maximum carrying capacity declined from $280 \cong m^{-2}$ for 10mm size classes to $4 \cong m^{-2}$ for the largest size classes. In poorer quality Gravel areas, potential densities declined from around $10 \cong m^{-2}$ to 1.6 or $1.0 \cong m^{-2}$. In other gravelly areas dominated by bedrock or sand, carrying capacities declined to as low as $0.6 \cong m^{-2}$. These calculations likely overestimate true carrying capacity. We assumed that all shelters greater than the minimum size are available but, of course, these could be occupied by older cohorts. The analysis of shelter size distributions also suggests that there is high availability of habitat for a large settlement cohort in the Val Comeau study area that would face habitat limitation when they grew to approximately 25-35 mm CL, using the laboratory-based scaling model. Under natural conditions, minimum shelter sizes are likely larger and habitat limitation would shift to smaller size classes.

These results suggest that: (1) availability of suitable habitat for juvenile lobsters is patchily distributed across a large range of spatial scales; (2) much of the Gravel substrates (38% of the 7 km^2 site area) would support high densities of small, post-settlement lobsters; (3) availability of cobble and boulder shelter habitats decline rapidly with increasing lobster body size; and (4) a relatively small fraction of Gravel substrates (15% of the total site area) could support high densities of juveniles through the shelter-restricted stages.

These results have important implications for future research and management practices. Research needs to quantify geographic variation in spatial scaling of lobster habitats; we should not assume that large areas of shallow coastal substrates are homogeneous in their carrying capacity for juvenile lobsters. Failure to take into account these types of patterns could impact the effectiveness of conservation measures.

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SPATIAL LINKAGES BETWEEN JUVENILE LOBSTER DISTRIBUTIONS AND FISHERY RECRUITS

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The rocky subtidal zone is characterized by high diversity of bottom types and organisms. Landscape ecology approaches this type of heterogeneity under the basic premise that the composition and spatial form of a landscape mosaic fundamentally affects the way ecological systems function. Landscape ecology provides conceptual and analytical approaches used for studying spatial pattern and scale. In our current work we are studying the spatial structure of coastal habitats for a range of scales from centimetres to kilometres using sidescan sonar, remote and diver-deployed video imaging, and physical sampling methods in two geologically different regions in eastern Canada.

We examined spatial patterns of lobster habitats at sites in Northern New Brunswick, Southwest Nova Scotia and the outer Bay of Fundy. Study sites were mapped using side-scan sonar mosaics which were subsequently ground-truthed using remote and diver operated video methods. Detailed habitat and lobster sampling, for a range of spatial scales, were conducted on 1 x 100m transects and on nested quadrats ranging from $0.25m^2$ to $25m^2$ in area. Differential GPS was used to geo-reference all sampled substrates and benthic organisms from video transect and quadrat data. In this report we set this research, which was directed at juvenile lobster distribution, in the context of the spatial distribution of fishery recruits which have the propensity to range over several km's, and which may exhibit distinct seasonal patterns in their occupation of nearshore habitats.

In contrast to the study site at Val Comeau in Northern New Brunswick where coastal topography permitted us to map one large area (7 km^2), we selected seven smaller areas, together totalling 12 km^2, at our study site in Lobster Bay, S.W. Nova Scotia. Approximately 12 km of remote camera and over 2000 m^2 of diver-held video images were completed for analyses of lobster habitats and 400 quadrats (0.25 m^2) were physically measured and searched in Lobster Bay. In additon to ground-truthing of side-scan sonar imagery, our remote camera survey approach proved useful in documenting spatial aspects of habitat occupation by relatively large lobsters.

Val Comeau consists of bedrock reefs, fissured bedrock with scattered fragments of relatively flat cobbles and boulders on sand. Habitat patches at the Val Comeau site were extremely complex and fragmented at large spatial scales. In contrast, Lobster Bay is made up of a diverse assemblage of habitats ranging from mud flats to shoals with large boulders originating from eroding mounds of glacial debris. Patch sizes were very large and fragmentation was low.

In Lobster Bay, lobster densities were high in structurally complex habitats compared with structurally simple sand or mud habitats. In addition, analysis of the spatial distribution of lobsters encountered on the remote video transects revealed that adult lobsters were also distributed on soft sediments and on large patches of horse mussels far from patches offering shelter. Size frequencies differed between Lobster Bay and Val Comeau. Lobster Bay had a greater size range of lobsters (22 - 134 vs. 15 - 89 mm CL) and a greater proportion of near and post- recruit size lobsters (46% > 50mmCL) than Val Comeau.

The geographical information system tools we have aquired and developed expertise in using in this project are now being adapted to access general lobster fisheries databases. We are now able to georeference lobster fishermen's catch settlement reports, science at-sea catch monitoring, and fishermen-sponsored catch monitoring with research data sets from this and other diving projects. This represents a major initial step along the road to eventually being able to build a spatially explicit lobster fishery production model.

PRELIMINARY ANALYSIS OF SETTLEMENT INTENSITY AND GROWTH OF JUVENILE LOBSTER IN THE SHALLOWS OF BAIE DE PLAISANCE, MAGDALEN ISLANDS

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Introduction

Science is still lacking the capacity to predict fishery recruitment of lobster (*Homarus americanus*) from the early stages of life. Linkages among egg production, zoeal and postlarval abundance, and environment have been investigated (e.g., Scarratt 1973; Harding et al. 1983; Hudon 1994). There is growing evidence that postlarval abundance and recruitment are correlated and both partly uncoupled from egg production (e.g., Miller 1997; Wahle and Incze 1997). However, direct investigation of the linkage between postlarval abundance, cohort strength at settlement, and subsequent levels of recruitment has been hindered by the difficulties for obtaining quantitative and statistically representative samples of settler abundance and for tracking the propagation of cohorts through time. In particular, there is relatively little information on the growth of juveniles from settlement to the late pre-recruit stages.

The present project was conducted to refine knowledge on growth of juvenile lobster, to determine the period of peak settlement, and to explore the potential for tracking lobster cohorts from settlement to recruitment. This research is complementary to the studies of Gendron et al. (2000) and Ouellet et al. (2000).

Methods

Lobster abundance in the shallows of the southern portion of Baie de Plaisance in the Magdalen Islands, which Hudon (1987) suggested to be a regular settlement area, has been monitored since 1995. Lobster settlement habitat at this site consists of a relatively narrow band of cobbles, rocks and boulders that extends from the shore to the deeper sand flats. In late summer or early autumn of each year, after the main settlement period, divers collected lobsters along randomly allocated transects set perpendicularly to the coast from the low water mark to the sand flats. Collection of lobsters was through a combination of belt- and suction-sampling. In 1997 and 1998, moreover, sampling was started in July for the purpose of determining the temporal pattern of settlement. Additionally, in 1998 we conducted an in situ experiment to determine relative growth per moult (carapace length [CL] increment at moult, expressed as a percentage of premoult CL), duration of intermoult, and maximum size for lobster at the end of the first year of growth. For this experiment, plankton-sampled postlarvae (instar IV) were placed individually in chambers that were moored in mid-August at our study site, at 2.5 m of depth. At least 2 times weekly the chambers were opened, lobsters were measured, any exuvium present was removed and conserved, and natural food items were introduced.

Results and Discussion

Based on 1997 and 1998 surveys, most of the settlement at our study site occurred in the first 3 weeks of August. Instars IV to X were easily resolved in cumulative size distributions for lobsters collected from 1995 to 1999. By the end of their first year of growth, lobsters of a given year-class were distributed in up to 3 successive instars, the smallest being instar VI and the largest being instar IX depending on individual and year.

Lobsters in the growth experiment completed 3 or 4 moults before the onset of winter, reaching an average CL of 9 mm at instar VII and of 11 mm at instar VIII. Larger postlarvae were more likely than smaller postlarvae to have reached instar VIII in their first autumn. Mean CL gradually diverged for successive instars between lobsters reared in situ and lobsters collected by divers, the wild lobsters being approximately 1-mm larger at instar VIII. This suggests that growth in the rearing experiment was suboptimal or that size-selective mortality occurred in the field. The pattern of growth inferred from the experiment and empirical data is one of regularly declining relative growth per moult with increasing size of lobster, consistent with most crustacean literature but very different from the erratic pattern derived by Hudon (1987).

The density of settlers, or year-class strength, varied considerably across the years. However, cohort strength was more easily and more consistently determined in the second than in the first year of benthic life, because divers catch the very small lobsters less effectively than the somewhat larger lobsters. Lobster year-classes were weak in 1995 and 1996, and increased from moderate to strong in the order 1998, 1997 and 1999. The difference in density between the weakest and the strongest of year-classes was approximately one order of magnitude.

Cohorts became increasingly difficult to resolve as time from settlement increased, due most probably to heterogeneous growth of individuals within a cohort. Nonetheless, a cohort was seemingly tractable for about 4-5 years after settlement, at which time lobsters had reached an average size of 50-60 mm CL and were within 2-3 moults (years) of recruiting to the fishery. Therefore, if the weakness of 1995 and 1996 year-classes is a geographically widespread phenomenon and if individuals from successive cohorts do not intermingle excessively (but see Sheehy et al. 1999), recruitment to the fishery may decline circa 2001-02.

Conclusions

This study has allowed a better resolution of juvenile lobster growth than was available to date for the Magdalen Islands. On a small geographical scale, cohorts can be recognised and tracked through time for several years. Although diver-based sampling is labour-intensive, the results are sufficiently encouraging to justify pursuit of the project for linkages to prerecruit surveys (Gendron et al. 2000) and for the goal of assessing natural mortality in the early stages of benthic life.

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EFFECTS OF CROWDING AND SHELTER LIMITATION ON THE BEHAVIOUR AND SURVIVAL OF THE FIRST BENTHIC STAGE OF LOBSTER

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Introduction

Lobsters shift from the planctonic to the benthic phase of their life at instar IV, and on the bottom they occupy existing shelters or excavate new shelters in soft substrates. Recently-settled lobsters are thought to be shelter-restricted (Lawton and Lavalli 1995) and may sustain themselves by suspension-feeding and browsing within their shelter or by ambush predation at their shelter's entrance (Barshaw and Bryant-Rich 1988; but see Sainte-Marie and Chabot 2000). It has been suggested that density-dependent competition for resources (shelter, food) among settlers is an important factor in lobster population demography and fishery recruitment (e.g., Fogarty and Idoine 1986, Wahle 1993), but no study has examined in detail the processes that condition survival of settlers.

This experimental laboratory study investigated how behaviour, growth and survival of instar V lobster change in relation to density and shelter availability.

Methods

Laboratory-cultured lobsters that had recently moulted from instar IV to instar V were used in two experiments. Circular tanks containing 4 housing units each with 8 numbered shelters were used for experiments (Fig. 1). The tanks were provided with a continuous flow of fresh temperature-controlled seawater. The contents of shelters could be examined by raising an opaque roof that covered a transparent ceiling.

The first experiment lasted for 24 days and examined with a 2-way factorial design (4 replicates of each treatment) the effects of shelter availability (8 [limited] or 32 [unlimited] open shelters) and stocking density (5 [low], 15 [medium] or 30 [high] lobsters per 0.5 m^2) on degree of lobster shelter fidelity and on growth and survivorship of lobsters. Two lobsters per replicate had a bee tag glued to their cephalothorax. The second experiment lasted for 11 days and examined with a 2-way factorial design (2 replicates of each treatment) the effects of shelter availability (limited versus unlimited) and stocking density (low versus high) on lobster shelter fidelity. All lobsters were identified with a numbered bee tag glued to their cephalothorax. Excess food was provided . Controls for the first experiment consisted of individually-reared lobsters.

Videotaping of lobsters in the low density treatment provided a record of their behaviour. Further, on a daily basis we collected exuviae and dead lobsters and counted survivors in the first experiment, and recorded associations of tagged lobsters with shelters in both experiments. At the end of the first experiment, carapace lengths were measured for all exuviae and dead and live lobsters, and we counted the number of missing limbs on surviving lobsters. Mortality was expressed as the percentage of dead individuals *relative to initial number of lobsters* in replicates or control.

Results and Discussion

All but one of the lobsters surviving at the end of the first experiment had moulted from instar V to instar VI. There was no density or shelter effect on moult increment, which averaged 17.3% in treatments compared to 17.6% in control. Size distribution data for lobsters that died in the course of the experiment indicated that death occurred after moulting. The cause of death was probably aggression, not food deprivation.

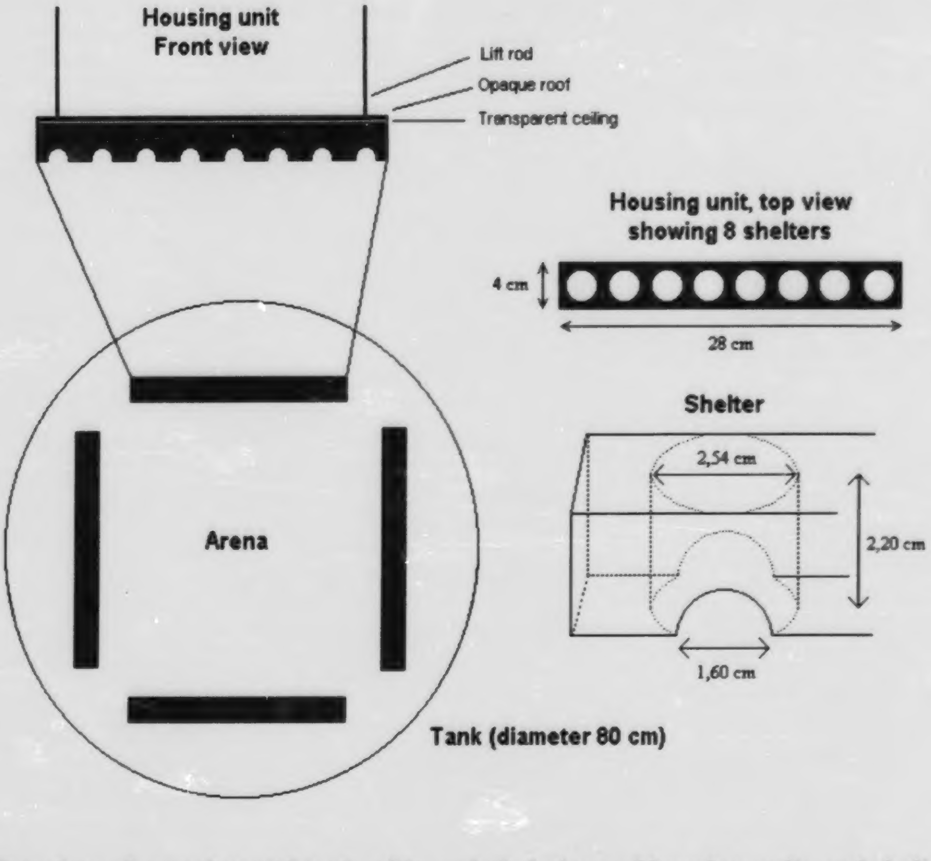
Housing unit
Front view
Lift rod
Opaque roof
Transparent ceiling
Housing unit, top view
showing 8 shelters
4 cm
28 cm
Shelter
2,54 cm
2,20 cm
1,60 cm
Arena
Tank (diameter 80 cm)

Fig. 1. Top view of experimental tank with exploded views of housing units and shelters.

At a given density, relative mortality was greater when shelters were unlimited than when they were limited. Relative mortality was also significantly higher in the low-density treatment than in the medium- and high-density treatments. Hence, the highest relative mortality (55%) occurred in the treatment combining unlimited shelter with low density, and the lowest relative mortality (20%, comparable to control at 15%) occurred in the treatment combining limited shelter with high density. The higher relative mortality in low-density treatments can be explained by the fact that dominance hierarchies are more rapidly established and tend to be sharper and temporally more stable in small than in large groups of individuals (e.g., Capelli and Hamilton 1984). However, the proportion of injured lobsters increased with increasing density, suggesting a potential for high mortality in the longer term.

The average number of shelters occupied by individual lobsters over the course of experiments declined with increasing density when shelters were limited, but was consistently greater and independent of density when shelters were unlimited. Lobsters exhibited greater fidelity to one shelter when shelters were limited and dominant lobsters tended to monopolise the shelters. Consistent with the above, video records of low-density treatments showed that shelter switching occurred much more frequently when shelters were unlimited than when they were limited. These observations can explain why mortality was higher in treatments with unlimited shelters than with limited shelters, the probability of agonistic shelter-based interactions being greater in the former group.

Overall, lobsters in the low-density treatment spent only 3-6% of their time out of shelters, in multiple brief bouts of activity, mostly to explore their environment and collect and hoard food back into their respective shelters. In a naturalistic environment, Barshaw and Bryant-Rich (1988) never observed early stage lobster in the open, but they did not monitor habitat continuously. In spite of the brevity and relative scarcity of interactions between unsheltered lobsters in our experiments, the result was a strong hierarchy and significant demographic effects for the cohort of lobsters.

Conclusion

Our results show that shelter availability and density may profoundly modify behaviour and survivorship of recently settled lobsters. The effects are some times counter-intuitive, as seen for example in the high relative mortality that occurred in the treatment combining low density with unlimited shelters. Fine behavioural observations of this type may be important for determining seeding densities and optimal design for artificial reefs and to understand how density-dependent processes operate to modify over time the cohorts of wild juvenile lobsters.

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ONTOGENIC SHIFTS IN DIET OF LOBSTER IN THE MAGDALEN ISLANDS

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Introduction

After the larval phase and settlement, lobsters (*Homarus americanus*) spend much of their time in burrows or natural shelters (Cobb 1971, Lawton 1987, Barshaw and Bryant-Rich 1988). Laboratory and field observations indicate that benthic lobsters grow through successive behavioural phases, changing from a strictly shelter-restricted habit to a more overt lifestyle involving short forays, lengthy excursions and even seasonal migrations away from the home range (Cooper and Uzmann 1977, Cobb and Wahle 1994). A variety of classifications have been proposed for these successive ontogenetic phases. The latest scheme, by Lawton and Lavalli (1995), recognises 5 phases: shelter-restricted juvenile (SRJ, ~4–14 mm cephalothorax length, CL), emergent juvenile (~15–25 mm CL), vagile juvenile (~25 mm CL to size of physiological maturity), adolescent, and adult.

Such changes in behaviour should be reflected in the diet of lobster. In the laboratory, lobsters smaller than 15 mm CL leave their burrows less than 5% of the time (Barshaw and Bryant-Rich 1988, Paille and Sainte-Marie 2000). They are able to draw plankton into their burrow and capture it, and ambush prey at the entrance of their burrow. Several authors have thus proposed that SRJs are mostly suspension feeders and ambush predators (Barshaw and Bryant-Rich 1988, Lavalli and Barshaw 1989, Lavalli 1991). However, the natural diet of SRJs has never been examined (Lawton and Lavalli 1995).

As they grow bigger and spend more time outside burrows, and as their claws become larger and stronger, lobsters should hunt larger and more mobile prey. Some studies of the diet of lobsters did not find any impact of size on diet (Weiss 1970, Ennis 1973, Hudon and Lamarche 1989). However, other studies pointed to ontogenetic changes in the frequency of different food items (Scarratt 1980, Carter and Steele 1982).

Our objectives were to describe the main prey items of lobster at one site of the Magdalen Islands, and size-dependent variations in diet. In particular, we wanted to verify whether or not SRJs were suspension feeders.

Methods

Lobsters were collected by scuba diving or suction sampling along a ~2 km rocky section of the south shore of Baie de Plaisance, Magdalen Islands. Water depth at the site varied from 1 to 7 m. A total of 476 lobsters (7.31–112.4 mm CL) were collected between 24 July and 31 Oct 1996. Another 38 lobsters (4.32–11.3 mm CL) were collected between 4 Aug and 13 Sep 1997 to increase the number of very small lobsters. There was no commercial fishery at or near our study site during either of the sampling periods; therefore food items cannot be discards or bait.

CL was measured with callipers. For most analyses, lobsters were grouped into 5-mm length-classes, except those ≥ 67.5 mm (mean = 77 mm), which were pooled into one length-class. Lobsters were dissected in the field within 2 hours of collection. Stomachs were excised and preserved in formalin diluted to 4% in seawater. In the laboratory, stomachs were opened and their contents were examined under a dissecting microscope. Identity of food items was determined to the highest taxonomic level possible, usually the species, using hard indicator fragments. Food boluses comprised of muscles/tissues that were not associated with hard parts, were identified only as "flesh". The proportion (in volume) of the organic fraction of the stomach content contributed by each food item was assessed visually in increments of 10%. The average contribution of each food category to stomach volume, and its frequency of occurrence (% of stomachs containing the food category) were calculated for each size-class of lobster. In the case of rock crab (*Cancer irroratus*), carapace width was estimated from the size of hard indicator fragments and predictive regressions established previously between the size of these indicator parts and carapace width of intact crabs. After stomach contents were examined, they were oven-dried (60°C to constant mass) and weighed. Six stomachs were excluded from analyses because they were not intact. Eight stomachs could not be weighed, but their contents were analysed. Only two stomachs were empty.

Results

There was a significant relationship was found between the dry mass of stomach content (in grams) and lobster CL (in mm):

$$\textbf{Dry mass of stomach content} = 7.967 \cdot 10^{-6} \times CL^{2.628} \; (r^2 = 0.51)$$

The food items found in lobster stomachs, as well as the average proportion of stomach volume attributed to each item after pooling lobsters into 5-mm length classes, are listed in Table 1. Some food items were grouped into major taxa for statistical analyses. The average contribution of these major taxa to stomach volume of each length-class of lobster is illustrated in Figure 1.

We did not find any evidence of suspension feeding (planktonic prey), even by the smallest lobsters. In general, the same prey are eaten by lobsters irrespective of size, although not always in the same proportions. Three prey items stand out from the others.

Rock crab accounted for < 10% of stomach volume in 7 mm lobsters, but this proportion increased linearly with lobster size, reaching about 50% in lobsters ≥ 65 mm. In terms of frequency of occurrence, less than 10% of the smallest lobsters had rock crab in their stomach, and this percentage increased to ~ 80% for lobsters ≥ 45 mm. In addition to having more rock crab in their stomach, larger lobsters tended to eat larger crabs than smaller lobsters did:

$$\textbf{Rock crab carapace width (mm)} = 1.1359 + 0.3964 \; \textbf{lobster CL} \; (r^2 = 0.34)$$

Bivalves accounted for almost 30% of stomach volume of 7-mm lobsters, but this proportion decreased linearly with lobster size, and bivalves made up about 5% of stomach volume of the largest lobsters. About 90% of lobsters ≤ 35 mm had bivalves in their stomachs, but this percentage decreased slowly with increasing lobster size, and only about half of the largest lobsters had eaten bivalves. Finally, unidentified flesh accounted for about 40% of stomach volume in 7-mm lobsters. This proportion decreased linearly to about 15% in 77-mm lobsters. Flesh was found in 60–70% of individuals for most length-classes, although this percentage was slightly higher (75–95%) for lobsters of 10–30 mm CL.

All other food items accounted for less than 10% of stomach volume, in any length-class. The frequency of occurrence of these items also tended to be lower than for the three main food items, although there were some exceptions in which frequency of occurrence was high relative to volume. This may indicate that a high proportion of lobsters eats such food, but always in small quantities. It is also possible that prey with a high proportion of soft tissues were digested more quickly, with a few hard parts remaining longer in the stomachs. These rarer prey items were usually eaten preferentially by lobsters of certain sizes, but the relationships between their contribution to stomach volume and lobster size were not linear.

Five food items were most abundant in smaller lobsters. Lobsters ≤ 45 mm had more polychaetes in their stomach than larger lobsters. Frequency of occurrence of polychaetes varied from 30 to 70% depending on lobster size, and tended to be higher for lobsters of intermediate size (25–45 mm). Very small lobsters (≤ 20 mm) tended to have more macroalgae, crustacean meiofauna or juveniles, amphipods and foraminiferans in their stomachs than large lobsters. Macroalgae were found in about 30% of stomachs for most lobster sizes, but up to 80% of lobsters ≤ 20 mm contained macroalgae. About 25–30% of 7-mm lobsters had crustacean meiofauna or juveniles, amphipods and foraminiferans in their stomachs, but very few, if any, lobster > 20 mm did.

Table 1 Contribution of each prey type to stomach content volume of lobster, averaged for each length class. Many rare food items were regrouped into major taxa (leftmost column) for statistical analyses. The three most abundant food items are shown with a grey background.

		Lobster size class (number of stomachs)													
Prey type	**Prey**	**7** (16)	**10** (35)	**15** (28)	**20** (38)	**25** (56)	**30** (45)	**35** (52)	**40** (51)	**45** (45)	**50** (45)	**55** (31)	**60** (25)	**65** (16)	**77** (21)
Foraminiferans		0.028	0.013	0.008	0.006	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.004	0.000
Macroalgae		0.071	0.073	0.059	0.052	0.036	0.032	0.028	0.032	0.034	0.026	0.039	0.031	0.028	0.042
Corallina officinalis		0.000	0.005	0.026	0.012	0.029	0.018	0.029	0.020	0.020	0.022	0.014	0.008	0.000	0.007
Hydrozoans		0.000	0.015	0.022	0.028	0.025	0.024	0.024	0.011	0.022	0.022	0.022	0.033	0.014	0.014
Bivalves		**0.406**	**0.258**	**0.195**	**0.141**	**0.181**	**0.219**	**0.175**	**0.148**	**0.143**	**0.164**	**0.099**	**0.078**	**0.050**	**0.041**
	Pelecypoda	0.214	0.116	0.040	0.027	0.047	0.058	0.029	0.035	0.042	0.024	0.018	0.036	0.027	0.011
	Mytilus edulis	0.000	0.004	0.014	0.009	0.026	0.040	0.030	0.028	0.019	0.028	0.016	0.020	0.000	0.000
	Modiouls modiolus	0.192	0.138	0.141	0.105	0.109	0.122	0.116	0.085	0.081	0.112	0.065	0.021	0.023	0.030
Gastropods		0.042	0.031	0.036	0.027	0.055	0.054	0.080	0.060	0.064	0.068	0.085	0.064	0.093	0.067
	Gastropoda	0.042	0.031	0.036	0.027	0.055	0.054	0.071	0.058	0.055	0.068	0.080	0.061	0.089	0.056
	Lacuna vincta	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.001	0.009	0.000	0.005	0.003	0.004	0.011
Polychaetes		0.084	0.060	0.051	0.056	0.066	0.054	0.081	0.065	0.062	0.044	0.051	0.046	0.050	0.050
	Polychaeta	0.005	0.002	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	Nereidae	0.069	0.022	0.012	0.015	0.020	0.030	0.042	0.038	0.043	0.026	0.040	0.032	0.035	0.047
	Polynoidae	0.010	0.036	0.039	0.042	0.045	0.024	0.038	0.026	0.019	0.018	0.011	0.015	0.014	0.003
Barnacles (*Balanus* sp.)		0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.003	0.001	0.002	0.000	0.005	0.000
Crustacean meiofauna or juveniles		0.043	0.017	0.011	0.004	0.014	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	Crustacea	0.023	0.011	0.003	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Harpacticoida	0.005	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ostracoda	0.015	0.006	0.008	0.004	0.003	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Amphipods		0.031	0.002	0.011	0.012	0.005	0.003	0.004	0.004	0.007	0.003	0.000	0.006	0.000	0.000
	Amphipoda	0.031	0.002	0.008	0.009	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Caprellidea	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.000	0.000	0.000	0.000
	Gammaridae	0.000	0.000	0.000	0.003	0.001	0.001	0.000	0.004	0.001	0.003	0.000	0.006	0.000	0.000
	Corophium sp.	0.000	0.000	0.003	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Prey type	Prey	Lobster size class (number of stomachs)													
		7 (16)	**10** (35)	**15** (28)	**20** (38)	**25** (56)	**30** (45)	**35** (52)	**40** (51)	**45** (45)	**50** (45)	**55** (31)	**60** (25)	**65** (16)	**77** (21)
	Gammarus sp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Isopods		0.000	0.019	0.008	0.007	0.004	0.008	0.008	0.009	0.006	0.003	0.007	0.006	0.000	0.000
	Isopoda Valvifera	0.000	0.002	0.008	0.002	0.004	0.005	0.006	0.007	0.001	0.000	0.002	0.003	0.000	0.000
	Idoteidae	0.000	0.017	0.000	0.002	0.000	0.002	0.000	0.002	0.000	0.001	0.000	0.003	0.000	0.000
	Idotea sp.	0.000	0.000	0.000	0.002	0.000	0.002	0.001	0.000	0.005	0.002	0.005	0.000	0.000	0.000
Shrimps		0.000	0.014	0.000	0.000	0.000	0.001	0.000	0.006	0.002	0.000	0.002	0.007	0.000	0.000
	Caridea	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
	Crangon septemspinosa	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.006	0.002	0.000	0.002	0.000	0.000	0.000
Hermit crabs		0.000	0.000	0.000	0.039	0.036	0.054	0.082	0.042	0.022	0.087	0.051	0.038	0.010	0.048
	Paguridae	0.000	0.000	0.000	0.039	0.036	0.054	0.069	0.042	0.013	0.069	0.030	0.038	0.010	0.048
	Pagurus acadianus	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.010	0.018	0.021	0.000	0.000	0.000
Rock crab		**0.023**	**0.128**	**0.124**	**0.136**	**0.197**	**0.178**	**0.276**	**0.303**	**0.377**	**0.291**	**0.364**	**0.444**	**0.510**	**0.474**
	Crustacea Decapoda (excl. *Homarus* and *Pagurus*)	0.023	0.083	0.095	0.112	0.099	0.051	0.122	0.057	0.045	0.081	0.051	0.144	0.181	0.235
	Cancer irroratus	0.000	0.045	0.030	0.025	0.097	0.127	0.154	0.246	0.332	0.210	0.313	0.300	0.329	0.239
Lobster (*Homarus americanus*)		0.000	0.007	0.003	0.000	0.007	0.000	0.006	0.007	0.010	0.010	0.000	0.003	0.044	0.033
Echinoderms		0.000	0.000	0.000	0.037	0.001	0.029	0.005	0.054	0.032	0.019	0.057	0.016	0.029	0.023
	Echinodermata	0.000	0.000	0.000	0.020	0.000	0.027	0.003	0.036	0.019	0.008	0.010	0.000	0.000	0.000
	Ophiuroidea	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000
	Strongylocentrotus droebachiensis	0.000	0.000	0.000	0.012	0.001	0.001	0.003	0.018	0.013	0.011	0.034	0.016	0.029	0.023
Fish		0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.006	0.007	0.038	0.004	0.080
Flesh		**0.271**	**0.358**	**0.445**	**0.444**	**0.342**	**0.322**	**0.198**	**0.237**	**0.193**	**0.233**	**0.201**	**0.182**	**0.159**	**0.122**

Table 1 Contribution of each prey type to stomach content volume of lobster, averaged for each length class. Many rare food items were regrouped into major taxa (leftmost column) for statistical analyses. The three most abundant food items are shown with a grey background.

Prey type	**Prey**	Lobster size class (number of stomachs)													
		7 (16)	**10** (35)	**15** (28)	**20** (38)	**25** (56)	**30** (45)	**35** (52)	**40** (51)	**45** (45)	**50** (45)	**55** (31)	**60** (25)	**65** (16)	**77** (21)
Foraminiferans		0.028	0.013	0.008	0.006	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.004	0.000
Macroalgae		0.071	0.073	0.059	0.052	0.036	0.032	0.028	0.032	0.034	0.026	0.039	0.031	0.028	0.042
Corallina officinalis		0.000	0.005	0.026	0.012	0.029	0.018	0.029	0.020	0.020	0.022	0.014	0.008	0.000	0.007
Hydrozoans		0.000	0.015	0.022	0.028	0.025	0.024	0.024	0.011	0.022	0.022	0.022	0.033	0.014	0.014
Bivalves		**0.406**	**0.258**	**0.195**	**0.141**	**0.181**	**0.219**	**0.175**	**0.148**	**0.143**	**0.164**	**0.099**	**0.078**	**0.050**	**0.041**
	Pelecypoda	0.214	0.116	0.040	0.027	0.047	0.058	0.029	0.035	0.042	0.024	0.018	0.036	0.027	0.011
	Mytilus edulis	0.000	0.004	0.014	0.009	0.026	0.040	0.030	0.028	0.019	0.028	0.016	0.020	0.000	0.000
	Modiouls modiolus	0.192	0.138	0.141	0.105	0.109	0.122	0.116	0.085	0.081	0.112	0.065	0.021	0.023	0.030
Gastropods		0.042	0.031	0.036	0.027	0.055	0.054	0.080	0.060	0.064	0.068	0.085	0.064	0.093	0.067
	Gastropoda	0.042	0.031	0.036	0.027	0.055	0.054	0.071	0.058	0.055	0.068	0.080	0.061	0.089	0.056
	Lacuna vincta	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.001	0.009	0.000	0.005	0.003	0.004	0.011
Polychaetes		0.084	0.060	0.051	0.056	0.066	0.054	0.081	0.065	0.062	0.044	0.051	0.046	0.050	0.050
	Polychaeta	0.005	0.002	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	Nereidae	0.069	0.022	0.012	0.015	0.020	0.030	0.042	0.038	0.043	0.026	0.040	0.032	0.035	0.047
	Polynoidae	0.010	0.036	0.039	0.042	0.045	0.024	0.038	0.026	0.019	0.018	0.011	0.015	0.014	0.003
Barnacles (*Balanus* sp.)		0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.003	0.001	0.002	0.000	0.005	0.000
Crustacean meiofauna or juveniles		0.043	0.017	0.011	0.004	0.014	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	Crustacea	0.023	0.011	0.003	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Harpacticoida	0.005	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ostracoda	0.015	0.006	0.008	0.004	0.003	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Amphipods		0.031	0.002	0.011	0.012	0.005	0.003	0.004	0.004	0.007	0.003	0.000	0.006	0.000	0.000
	Amphipoda	0.031	0.002	0.008	0.009	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Caprellidea	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.000	0.000	0.000	0.000
	Gammaridae	0.000	0.000	0.000	0.003	0.001	0.001	0.000	0.004	0.001	0.003	0.000	0.006	0.000	0.000
	Corophium sp.	0.000	0.000	0.003	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Prey type	Prey	Lobster size class (number of stomachs)													
		7 (16)	**10** (35)	**15** (28)	**20** (38)	**25** (56)	**30** (45)	**35** (52)	**40** (51)	**45** (45)	**50** (45)	**55** (31)	**60** (25)	**65** (16)	**77** (21)
	Gammarus sp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Isopods		0.000	0.019	0.008	0.007	0.004	0.008	0.008	0.009	0.006	0.003	0.007	0.006	0.000	0.000
	Isopoda Valvifera	0.000	0.002	0.008	0.002	0.004	0.005	0.006	0.007	0.001	0.000	0.002	0.003	0.000	0.000
	Idoteidae	0.000	0.017	0.000	0.002	0.000	0.002	0.000	0.002	0.000	0.001	0.000	0.003	0.000	0.000
	Idotea sp.	0.000	0.000	0.000	0.002	0.000	0.002	0.001	0.000	0.005	0.002	0.005	0.000	0.000	0.000
Shrimps		0.000	0.014	0.000	0.000	0.000	0.001	0.000	0.006	0.002	0.000	0.002	0.007	0.000	0.000
	Caridea	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000
	Crangon septemspinosa	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.006	0.002	0.000	0.002	0.000	0.000	0.000
Hermit crabs		0.000	0.000	0.000	0.039	0.036	0.054	0.082	0.042	0.022	0.087	0.051	0.038	0.010	0.048
	Paguridae	0.000	0.000	0.000	0.039	0.036	0.054	0.069	0.042	0.013	0.069	0.030	0.038	0.010	0.048
	Pagurus acadianus	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.010	0.018	0.021	0.000	0.000	0.000
Rock crab		**0.023**	**0.128**	**0.124**	**0.136**	**0.197**	**0.178**	**0.276**	**0.303**	**0.377**	**0.291**	**0.364**	**0.444**	**0.510**	**0.474**
	Crustacea Decapoda (excl. *Homarus* and *Pagurus*)	0.023	0.083	0.095	0.112	0.099	0.051	0.122	0.057	0.045	0.081	0.051	0.144	0.181	0.235
	Cancer irroratus	0.000	0.045	0.030	0.025	0.097	0.127	0.154	0.246	0.332	0.210	0.313	0.300	0.329	0.239
Lobster (*Homarus americanus*)		0.000	0.007	0.003	0.000	0.007	0.000	0.006	0.007	0.010	0.010	0.000	0.003	0.044	0.033
Echinoderms		0.000	0.000	0.000	0.037	0.001	0.029	0.005	0.054	0.032	0.019	0.057	0.016	0.029	0.023
	Echinodermata	0.000	0.000	0.000	0.020	0.000	0.027	0.003	0.036	0.019	0.008	0.010	0.000	0.000	0.000
	Ophiuroidea	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000
	Strongylocentrotus droebachiensis	0.000	0.000	0.000	0.012	0.001	0.001	0.003	0.018	0.013	0.011	0.034	0.016	0.029	0.023
Fish		0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.006	0.007	0.038	0.004	0.080
Flesh		**0.271**	**0.358**	**0.445**	**0.444**	**0.342**	**0.322**	**0.198**	**0.237**	**0.193**	**0.233**	**0.201**	**0.182**	**0.159**	**0.122**

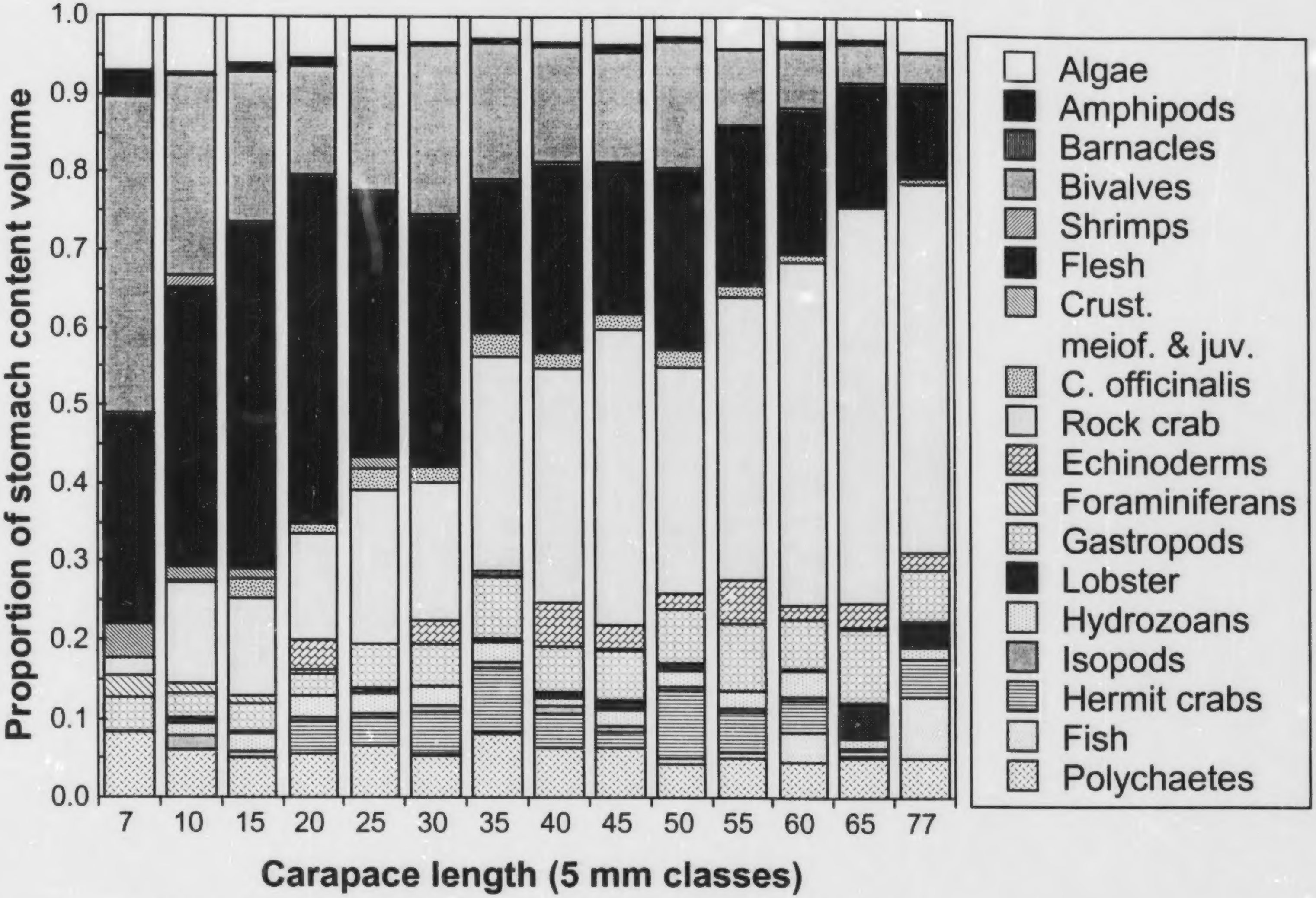

Figure 1 Average contribution of each prey type to the stomach content volume of lobsters.

Three food items were most abundant in large lobsters. Gastropods, for instance, accounted for only 3–4% of stomach volume in lobsters < 25 mm, but this increased to 6–8% in lobsters ≥ 35 mm. The same trend was observed in frequency of occurrence, which was only 30–50% in lobsters < 25 mm, but was > 60% in lobsters ≥ 35 mm. Cannibalism was rare, as lobster contributed ≤ 1% to stomach volume, and was found in ≤ 5% of stomachs, for lobsters < 65 mm. Even in larger lobsters, lobster prey accounted for < 5% of stomach volume, and was seen in less than 20% of stomachs. Similarly, fish was < 1% of stomach volume, and was seen in less than 10% of stomachs, for lobsters < 60 mm. In larger lobsters, the contribution of fish increased to 1–8% of stomach volume, and the frequency of occurrence increased to 10–20%.

Five other food items, hermit crabs, echinoderms, the alga *Corallina officinalis*, hydrozoans and isopods, tended to make up a greater proportion of stomach volume in lobsters of intermediate size (about 20–60 mm), but they never contributed more than 9% of stomach volume. Frequency of occurrence, which was always < 35%, also tended to be greater for lobsters of intermediate size. Finally, barnacles and shrimps were rare in volume (< 1%) and frequency of occurrence (< 10%), irrespective of lobster size.

Even though all length-classes of lobster contained the same food items, and the proportions of each prey type tended to vary gradually with lobster size, some natural groupings of lobsters could be recognised. A cluster analysis on the volume contribution of each prey type to each length-class (Ward's method after standardisation of the data) recognised 4 clusters: 7 mm, 10–20 mm, 25–60 mm and 65–77 mm. The first three components obtained by factor analysis (principal component analysis of standardised contribution in volume of each prey type, followed by varimax rotation) explained 69% of the total variance, and showed essentially the same natural groupings of lobster length-classes found in cluster analysis.

Discussion

We found no planktonic organism in any stomach, and thus no evidence that even the smallest lobsters (instar V) rely on suspension feeding. Food items eaten by the smallest lobsters in this study (7 mm) could be acquired within or at the entrance of the burrow, but it is not excluded that these lobsters leave their burrow to acquire some of their food.

Lobsters are known to bring food back to their burrow (Wickins et al. 1996, for European lobster, *Homarus gammarus*). The great majority of lobsters ≤ 20 mm were found under or in close proximity of the burrows of larger lobsters. Interestingly, these small lobsters also had more unidentified flesh in their stomach than larger lobsters. Considering their small size, it is unlikely they could have overcome any prey susceptible of providing flesh boluses clean of any hard part. Taken together, these facts suggest small lobsters obtain food particles from food items brought back by the larger lobster(s) living near them (commensalism). This would reduce the need to venture outside the burrow. Furthermore, the presence of larger lobsters would decrease predation risk when small lobsters do leave their burrow.

Although the abundance of rock crab, bivalves and unidentified flesh, the three most important prey items, changes gradually with lobster size, taking all the food items into account showed natural breaks in diet around 7–10 mm, 20–25 mm, and again around 60–65 mm. This agrees well with the classification of ontogenic phases suggested by Lawton and Lavalli (1995).

Management implications

If unidentified flesh boluses so commonly found in the stomachs of small, cryptic lobsters are indeed obtained from adolescent or adult lobsters living nearby, survival and growth of the first few benthic stages of lobster could be dependent upon the density of larger lobsters.

Artificial shelters are often suggested as a means to increase the carrying capacity of the environment for small, cryptic lobsters. Our data suggest that to improve lobster productivity, such shelters would have to provide appropriate habitat for benthic fauna on which juvenile lobsters prey. Moreover, as stated above, such shelters should provide appropriate burrows for larger lobsters to improve growth and survival of cryptic lobsters. Finally, factors decreasing density of rock crabs could be deleterious to lobsters of all size classes.

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EVALUATION OF ATLANTIC COD PREDATION ON AMERICAN LOBSTER IN THE SOUTHERN GULF OF ST. LAWRENCE, WITH COMMENTS ON OTHER POTENTIAL FISH PREDATORS.

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Abstract*

Demersal fishes are widely thought to be an important source of natural mortality for juvenile American lobster *Homarus americanus*. There were no significant relationships between abundance indices of American lobster and the dominant demersal fish species, Atlantic cod *Gadus morhua*, in the southern Gulf of St. Lawrence. American lobster was found in only one of 22,625 Atlantic cod stomachs collected between 1955 and 1980 – a period of low American lobster abundance. Only six of 12,008 Atlantic cod collected between July 1990 and October 1996 (a period of high American lobster abundance) had eaten American lobster. Most size-classes of the two species were spatially separate from early July to early September and November to May. American plaice *Hippoglossoides platessoides*, the second most abundant demersal fish species, did not eat American lobster (n = 1,800 stomachs). Again, the two species were spatially isolated for most of the year. More limited studies (in terms of spatial or seasonal coverage) on the diets of eight shallow water fish species (n = 4,674 stomachs) detected consumption of American lobster by shorthorn sculpin *Myoxocephalus scorpius*, cunner *Tautogolabrus adspersus*, and white hake *Urophysis tenuis* but not by winter flounder *Pleuronectes americanus*, yellowtail flounder *P. ferruginea*, thorny skate *Raja radiata*, spiny dogfish *Squalus acanthias*, or Greenland cod *Gadus ogac*. This study eliminated Atlantic cod, Greenland cod, American plaice, yellowtail flounder, winter flounder, and thorny skate as important predators of American lobster in the southern Gulf of St. Lawrence; however, the question of which of the remaining demersal fish species are important predators of American lobster remains largely unresolved.

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SESSION 3: CATCHABILITY

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The Catchability component of CLAWS evaluated factors affecting the capture of lobsters in traps. Understanding catchability is fundamental to improved assessments of lobster stock status, because most assessments are based on commercial trap data. Improved understanding of lobster catchability would also benefit the planning of fishery-independent surveys of abundance, since traps are the only sampling option in some areas. Lobster catchability is affected by lobster behavior, which in turn is affected by the physical environment (e.g. temperature). The physical design of traps and fishing strategy is also important. Different components of the lobster population (distinguished by for example size and sex) have different catchabilities.

The first paper in the Catchability session described the results of studies comparing the lobster catch of traps with different hoop sizes, and the catch of lobsters in tangle nets. The hoop sizes tested did not have as large an influence on the catch as was thought, but this work needs to be repeated in an area where lobsters are larger. The comparison of the trap catch with that collected by tangle nets produced some exciting results. Lobsters > 150 mm CL were captured in the tangle nets but were not seen in the traps. How numerous and important these large lobsters are in egg production needs further study.

The second paper presented was based on comparisons of the trap catch with that observed by divers in well-defined areas. These studies were focussed in the Baie de Chaleurs and in Lobster Bay and were heavily field oriented. Differences in catchability between the two areas may be related to the different sizes of lobsters in the two areas. Males were much more catchable than females in late summer, but in spring this difference was diminished. Larger lobsters seen on the bottom appear to be under-represented in traps, but because of the relatively small sample size, this finding is tentative.

Another contribution to the Catchability session demonstrated the importance of daily changes in bottom temperature to lobster catchability through analyses of lobster catch rates from voluntary fishing logs. It demonstrated how wind and coast line orientation affect bottom temperature, and hilighted the benefits of exploring information generated by fishermen.

The final paper of the session was based on autumn trap surveys done prior to CLAWS. The analysis demonstrates the potential for short-term changes in average catch rates due to weather. If annual trap surveys are to be useful to detect annual changes in abundance, they need to either estimate catchability for each survey , or the surveys need to be repeated several times within the year.

SIZE COMPOSITION OF AMERICAN LOBSTER, *HOMARUS AMERICANUS*, CATCHES USING TRAPS FITTED WITH DIFFERENT ENTRANCE DIAMETERS AND WITH TRAMMEL NETS

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The purposes of these studies were to determine (i) the effect of trap entrance ring diameter on the size composition of lobsters and (ii) if there is a significant proportion of the American lobster, *Homarus americanus*, population that has a low incidence of being captured by traps. The sampling procedure for the latter objective was especially aimed at large carapace length (CL) lobsters (>100mm CL) which are usually not found in traps in the study area, and are generally believed to be absent from the fishing grounds during the commercial seasons.

Lobster catchability was first assessed with traps fitted with different entrance diameters: 6.4 cm (2.5"), 12.7 cm (5"), and 16.5 cm (6.5"). Studies were conducted in the Baie des Chaleurs (off Stonehaven, and in the Caraquet region), in September of 1996. Results from these studies indicated that traps with the small entrances (6.4 cm) were efficient in keeping large lobsters from entering the traps, but were no more efficient at capturing small lobsters. The two larger size entrances (12.7 and 16.5 cm) showed no significant differences in the size composition of the lobster caught (see Tremblay et al. 1998 for results of the Stonehaven study). This may be because of the relative scarcity of large lobsters in the area. Unpublished studies from the 1970's off eastern Nova Scotia indicate larger rings (7") do yield a greater number of large (> 140 mm CL) lobsters. This finding needs to be verified.

The 1996 studies were followed in 1997 and 1998 by a qualitative study of sex and size-specific catchability at four sites in the Caraquet region. Sampling was conducted during the molting period in July and August and again in late September and November using lobster traps and trammel nets. The traps were similar to the ones used in 1996 with the exception that traps with small entrance diameter (6.4 cm) were not used. The trammel nets were 91m in length with 16.5 cm (6.5") mesh size. Male lobsters were found to greatly dominate the sex ratio (male/female) in the traps (1.8) but especially in the nets (4.7). Size composition was much smaller in the traps with both the 12.7 cm and the 16.5 cm entrance diameters, with an overall mean size of 80 mm CL. The nets captured larger lobsters from all sites with a mean size of 112 mm CL (Lanteigne unpublished data).

Although important quantities of large sized lobsters were observed in the study area, it is difficult to assess the overall impact of these animals in terms of egg production. Differences in molt timing and seasonal migration of males and females may explain the low abundance of females. The presence of these large lobsters on the fishing grounds may have an impact on egg and larval production in the area. Size-specific seasonal variation in vulnerability and catchability is evident in this population of lobster as study catches vary both with time and space.

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LOBSTER CATCHABILITY ESTIMATES FROM COMPARISONS OF THE TRAP CATCH WITH THE POPULATION STRUCTURE OBSERVED WHILE DIVING

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Lobster traps are very selective for certain components of the lobster population. To obtain a less biased picture of the true population structure of lobsters, the catchability project within CLAWS utilized underwater counts along transect lines using SCUBA. Emphasis during diving was on lobsters with carapace lengths (CL) > 50 mm CL, since smaller lobsters would escape through the mesh of most lobster traps. The approach was to locate habitats that were searchable by divers. This eliminated areas deeper than about 20 m as well as those with large immovable boulders, stacked boulders or dense kelp. Study areas were 200-400 m long by 150 m across. Each study area was demarcated by a groundline from which transects were set for divers. A standard research trap was used in all areas; traps with different entrance ring diameters and commercial traps were also examined. Altogether there were five area-season combinations: off Stonehaven in the Baie des Chaleurs in Aug. 1996, and in Lobster Bay in June 1997, Sept. 1997, Sept. 1998 and June 1999. Catchability (q) for males and females of different sizes was estimated by dividing the average catch rate in traps by the density measured from SCUBA. This quantity is also known as effective fishing area, and is expressed in terms of area (m^2) per trap.

Off Stonehaven, in the Baie des Chaleurs, estimates of q for lobsters < 66 mm CL were 16-49 m^2 per trap (12.7 mm rings), and 453-860 m^2 per trap for lobsters 66-86 mm CL (Tremblay et al. 1998). Compared to previous studies off coastal Nova Scotia, the Stonehaven estimates are comparable for the smaller sizes, but are considerably higher for lobsters 66-86 mm CL. The small size of lobsters at Stonehaven relative to the coastal Nova Scotia sites may explain the difference, as the presence of large lobsters may reduce the catch of small lobsters. Population size structure may be an important variable affecting lobster catchability. Male lobsters 76-86 mm CL were more catchable than females of the same size as has been observed elsewhere in late summer (Miller 1995).

As in other studies, catchability in Lobster Bay was lowest for lobsters 50-60 mm CL, ranging from 0-72 m^2 per trap. Catchability generally increased with size until between 100-120 mm CL where it levelled off or declined. Combining all the data from the different seasonal studies in Lobster Bay, it was noted that the largest lobsters seen during diving were under-represented in the research traps. During the 90 dive transects (each 150 m long and 2 m wide) 7% (n=25) of the 355 lobsters greater than or equal to 81 mm CL (legal size, or LS) were larger than 120 mm CL. By comparison, in 167 hauls of research traps, less than 1% (n = 4) of the LS lobsters were larger than 120 mm CL. Commercial traps were used in addition to the research traps in 1997 and they also caught fewer large lobsters. During diving 7% (n = 15) of the LS lobsters were larger than 120 mm CL, but in the commercial traps the fraction was only 2% (n = 5). Together these data corroborate other studies indicating underselection of large lobsters by traps.

Accounting for the presence of large, under-selected lobsters on the lobster grounds would tend to lower estimates of total mortality. As a first approximation of this effect, length-based cohort analysis was applied to (i) the numbers at size from the combined research trap data and (ii) the numbers at size from the combined dive surveys. The estimate of total mortality based on the trap data was 63%; that from dive data was 44%. Accounting for large animals is important for estimates of mortality.

Prior to CLAWS, the few estimates of catchability for lobsters were for late August-September. As these were well outside the commercial fishing season, this study undertook the first estimates of lobster catchability for June, shortly after the closure of the commercial season in Lobster Bay. The 1997 work is described in Tremblay 2000. The June q estimates were different than those from late summer. Females > 80 mm CL were more than 3 times as catchable as in September, and more catchable than males of the same size. The apparent higher catchability of females in late spring provides an explanation for the relative increase in larger females seen in the catch during the fishery. During May the catch rate of large females (greater than 100 mm CL) typically increases. This appears to be due at least partially to a late spring increase in the catchability of this group of lobsters.

Acknowledgements

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INTERACTION OF WIND, TEMPERATURE AND THE CATCH RATE OF AMERICAN LOBSTER (*HOMARUS AMERICANUS*) DURING SPRING

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Fishermen frequently list wind as an important determinant of catch rate. Wind from a particular direction will result in good catches, while wind blowing from the opposite direction will tend to drive catches down. The wind directions that produce good and poor catches are site dependent, however. Wind could affect lobster catchability by modifying bottom temperature, which in turn can affect lobster activity. In this paper, we explore the relationships among wind, temperature and daily catch rate using 3 years of data for up to 7 ports in northeastern New Brunswick and 3 years of data for 8 ports on the east and south coasts of Cape Breton. Two hypotheses are tested. The first is that temperature affects the catch-per-unit-effort (hereafter referred to as catch per trap haul, i.e. CPTH). The second hypothesis is that the temperature variability in these regions is principally wind driven.

Lobster landings and trap haul data were obtained from fisherman through a voluntary logbook program. Data were collected in 1994 to 1996 in the Baie des Chaleur region. Sites stretched from New Mills at the head of the bay to Val Comeau, which is located on the eastern shore of New Brunswick facing the Gulf of St. Lawrence. On Cape Breton Island, there were 5 sites on the eastern coast from Aspy Bay to False Bay and 3 on the southern coast from Louisbourg to Petit de Grat. From the landings and trap haul data, the catch per trap haul (CPTH) in kg was calculated. Hourly to 2 hourly records of temperature were obtained at a series of moored sites near where the traps were hauled, or from instruments placed directly in the traps. Wind data were obtained from the Atmospheric Environment Service for Miscou in the Baie des Chaleur and for Sydney and Hart Island in Cape Breton.

Because the efficiency of the traps varies depending upon the time between hauls, we restricted our analyses to 1-day soak times. Daily average temperatures were estimated from the 1 to 2 hourly data for the period from 8 a.m. of one day to 8 a.m. of the next day. This corresponds closely to the time period between trap hauls. The landings and temperatures were first-differenced to remove any linear trends in the time series. We also restricted the analysis to the first 4 weeks of lobster season in the case of the Baie des Chaleur and 5 weeks for Cape Breton. This reduces the complicating effect that molting may have on catch and also eliminates CPTH data later in the lobster season that generally have a low signal to noise ratio. The longer time for Cape Breton is justified on the basis of later molting. We also combined data from all available years for each site for our analyses.

Results show that at both Baie des Chaleur and Cape Breton, temperature has a statistically significant effect upon catchability of lobsters. These were established using correlation analysis and also by using the binomial test based on the scattergrams of the first-differenced temperatures and CPTH where coordinates of the paired variables located in the upper right (+/+) or the lower left (-/-) quadrant indicated a good correlation. The two methods produced similar results. In the

Baie des Chaleur region, 6 of the 7 sites were significantly correlated with the temperature variability accounting for from 15 to 60% of the variance in CPTH, depending upon site (Fig. 1). On the eastern shore of Cape Breton, changes in CPTH were significantly correlated with temperature variability for 4 of the 5 sites (changes in temperature accounting for from 5 to over 80% of the CPTH variance). None of the sites along the Atlantic coast produced significant correlations. Differences in the strength of the correlations between sites are in part associated with the amplitude of the temperature fluctuations (Fig. 2). Higher temperature variability tends to result in higher correlations with changes in lobster landings.

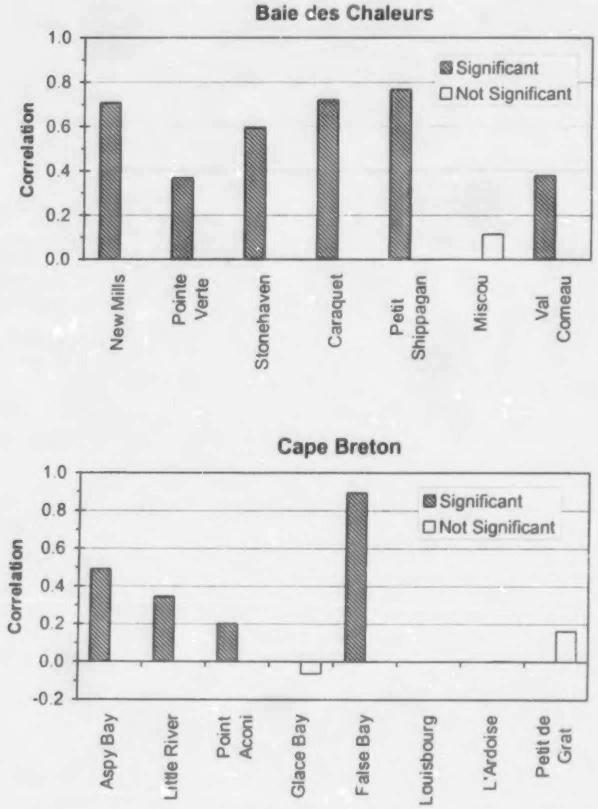

Fig. 1. The correlation coefficient between the daily changes in catch per trap haul (CPTH) and temperature from sites in the Baie des Chaleurs (top panel) and off Cape Breton Island (bottom panel).

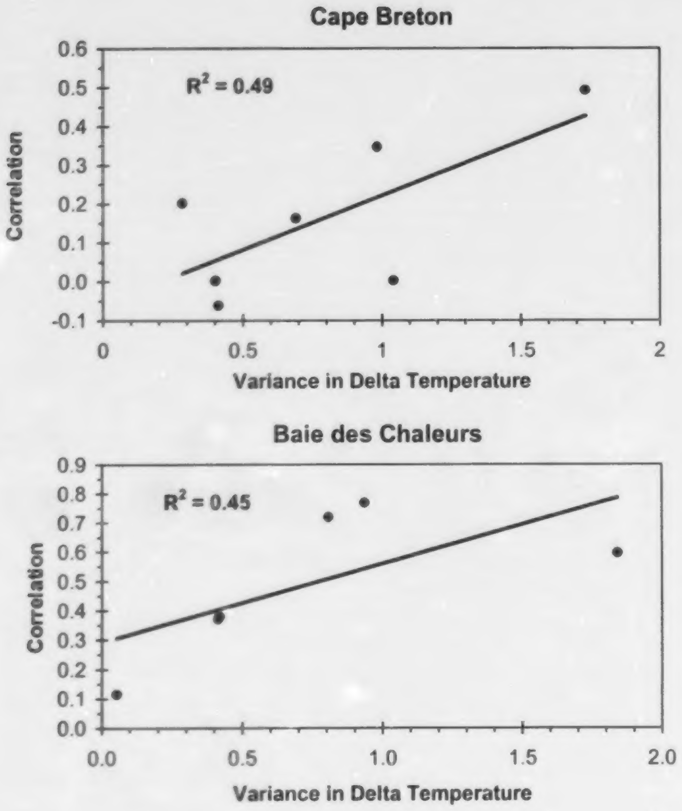

Fig. 2. The strength of the correlation between daily changes in CPTH and temperature as a function of the amplitude of the temperature variability (variance) for sites in the Baie des Chaleurs (top panel) and around Cape Breton Island (bottom panel).

In both regions, the temperature variability is at a maximum at periods of 5-10 days and within each region these fluctuations are well correlated between sites. Coherence between temperatures and the wind show a peak at these periods. In all regions, temperatures respond primarily to alongshore winds. Warmer waters are produced by winds blowing alongshore with the coast on the right looking downwind, while colder waters are produced when the coast is to the left of the wind. This is consistent with the classical Ekman response with wind-induced downwelling when the coast is on the right and upwelling when the coast is on the left. For the sites on the southern shore of the Baie des Chaleur, east/west winds produce the largest response whereas outside of the bay at Val Comeau, temperatures respond mainly to north/south winds. On the eastern coast of Cape Breton, the north/south winds also tend to maximize the temperature variability. We conclude that winds do affect catchability of lobsters in a manner generally consistent with the observations of fishermen.

FISHERY-INDEPENDENT TRAP SURVEYS FOR LOBSTERS–DESIGN CONSIDERATIONS

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Lobster assessments rely heavily on data from the commercial trap fishery. These data include length frequencies that are used to estimate exploitation, and catch rate data that are used as an index of abundance for some fishing areas. While these data are readily available, there are risks in basing assessments entirely upon data from commercial traps. Lobster catchability in baited traps is variable and affected by biological and environmental factors. Lobster catchability is also affected by trap design and fishing strategy, and the extent to which these evolve over time is a factor that needs consideration when analysing annual changes in catch rate.

One way of reducing the risks associated with relying totally on commercial data is to develop fishery-independent surveys in relatively small index areas. These surveys could be conducted using diving (high quality data but also high cost and limited by depth and habitat), towed cameras (size and sex data limited, relatively low cost, limited by habitat), trawling, or trapping. With controlled fishing the biases of traps can at least be controlled and accounted for. In this paper some of the design considerations for a trap survey are considered.

Data used to address these questions came primarily from trap surveys conducted off Little River (northern Cape Breton) in 1994 and 1995 to predict the relative abundance of incoming recruits. Although the surveys were discontinued prior to CLAWS, they provide an excellent data source to evaluate trap survey design.

The Little River surveys were in an area of 2 km by 6 km, and in 1995 were repeated twice, providing a unique opportunity to test for within-season differences in survey estimates. Trapping took place in the second half of September, after the major molting period. Each survey took place over 4 days (an initial set day and 3 days of hauling and resetting). Survey design was proportional allocation within area/depth strata. Each of the 15 strata was approximately 2000 m long by 300 m across. No attempt was made to eliminate areas of soft bottom, where lobsters might be less abundant. Sampling depths ranged from 1.5-27 m. The latitudes and longitudes of setting locations were randomly detemined prior to the survey; the stations were located during the survey with a global positioning system (GPS). Trawls of 3 traps each were set in an east-west direction (across the major tidal currents) and reset to random positions each day. The density of the traps was about 15 per km2 on each of the 3 days. In the 1994 survey it was noted that the central trap (~ 18m from the outer 2 traps), caught 68% as many lobsters as the outer traps. In 1995 the distance between traps was increased to 33 m; this diminshed the apparent overlap but the middle trap still caught only 84% as many lobsters as the outer two. Further analyses were resticted to trawl totals.

The number of lobsters caught per trawl in 1995 was modelled as a Poisson random variable. A log-linear model was used to test hypotheses concerning differences between numbers caught.

Three models were tested, a null model which fitted an overall mean over the three days of the survey, a model which included strata as factor levels and the third model which included days within a stratum. Choice of best model was done using a nested analysis of deviance with a χ^2 test. For each survey the model was run for males 70-80 mm CL (male size group 3, or M3), males 81-93 mm CL (M4) and females of the same sizes (F3 and F4). In all runs the effect of strata was highly significant. The test for a difference between days was not significant except for F3's from survey 2.

The precision of the surveys (standard error/stratified mean) was dependent upon size, sex and survey, ranging from 4.3% to 10.2%. Confidence intervals were such that changes in catch rate of greater than 20 percent would be detectable for those size/sex groups with means (number per trawl) of 3 or greater (e.g. males and females 70-80 mm CL and males 81-93 mm CL). Confidence intervals based on bootstrapping confirmed the size of the confidence intervals.

To test for differences between the two surveys conducted in 1995, a Poison log-linear model was again used assuming no difference between days within a survey. For each of the 4 size/sex combinations there were significant differences between surveys, with the second survey showing fewer lobster than the first. The difference between the 2 surveys is thought to be weather related. Compared to survey #1 temperatures at 20 m were about 1.5 °C lower during the second survey. Perhaps more importantly moderate winds from the east on Sept 25-26 caused a heavy swell to develop that may have inhibited lobsters from entering the traps.

Analysis of the effect of stratification indicated gains of 12-31% over an unstratified design. The size of the gain was dependent upon size, sex, and survey. This indicates that the sample number per stratum could not be optimized for all size/sex combinations.

The analyses of trapping data from Little River indicate:

1. Stratification can improve the precision of trapping surveys.

2. Trap surveys with a density of 45 trap hauls per km^2 (15 traps per km^2 over 3 days) can have high precision but because of within-season variability significant differences in catch rate can occur over a period of 1-2 weeks. These differences probably result from catchability changes.

3. Abundance indices based on trap surveys need to account for possible short-term changes in catchability. This could be accomplished by estimating catchability for a portion of the area of each trap survey, or by repeating the trap survey several times within the season of interest.

SESSION 4: ASSESSMENT PARAMETERS

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The assessment component of CLAWS aimed at improving the assessment tools for evaluating the health of lobster stocks and the level of fishing mortality, and to develop models to evaluate management measures. Following the FRCC report it was clear that new methods were needed as the existing tools were inadequate for the new assessment demands. There were several major components to the program: development and refinement of growth and mortality models for calculating egg per recruit (E/R) and evaluating new conservation tools; evaluation of the relationship between fishing effort and fishing mortality (F); evaluation and testing of methods for estimating F, and reviewing potential reference points for the fishery.

The first paper on the relationship between fishing effort and F presented results of a simulation model that provided a measure of the impacts of temporal changes in fishing effort on fishing mortality, and incorporated spatial dynamics of the resource and the fishing fleet. Results of the simulations showed how various scenarios in the fishery would affect F. The model suggests that the present spatio-temporal allocation of fishing effort (inshore-offshore) by the fishing fleet maximises catches. The model suggested that recent changes in fishing strategies from an interception to a pursuit strategy have resulted in an increase in F. Industry proposals to reduce fishing effort would have a marginal effect on fishing mortality. The model also showed that the timing of fishing effort is important because of within-season changes in catchability. Development of models like this help biologists, managers and fishermen to better understand the dynamics of the fishery and impact of fishing or management changes

The second paper looked at methods available to estimate F. Accurate estimates of F have not been available in lobster assessments and are vital to understanding the fishery. The paper examined two methods using catch-effort and tagging data. Results were based on previous field observations and computer simulations. The strengths and weaknesses of each method were presented as well as their underlying assumptions. Tagging experiments yielded the best results with the estimated values closer to the real values simulated but tagging studies present special problems, require participation of large numbers of fishermen, are costly, and represent a major investment of time. The catch-effort method is easier to manage than tagging experiments as only the participation of a small group of fishermen is required in the studied area. However, since catch-effort estimators are affected by variable catchability, further studies on the catchability of lobsters are required before the method can be used with any certainty.

The next two papers looked at methods of estimating E/R and measuring the effects of management tools on egg and yield per recruit. The first paper using the Idoine-Rago simulation model looked at the effect of different management and fishing strategies using the Canadian and American nearshore waters of the Gulf of Maine as an example. The results showed that the benefits of both management regimes are better realised at low exploitation rates. This is simply the manifestation of allowing the lobsters to express those traits that give them protection from harvesting. At high exploitation rates the females are caught before their reproductive potential is realised. When the harvesting rate is low, more animals will mature and measures such as protection of berried females, v-notching and maximum size will have greater value. It appears that the most effective way to provide sustainable lobster resources is to reduce the harvesting rates. The gains in yield, and potential decrease in costs associated with harvesting, should make this an attractive avenue to pursue.

The next paper presented a second model that incorporated uncertainty that arises from the natural variability of lobster production processes (growth, natural mortality and recruitment) or from the difficulty in measuring these processes. The model provides a series of values of E/R from which cumulative frequency distributions can be computed to make probabilistic statements leading to risk evaluation. The model also offered a relative time frame for the management measures to be 100 % operational, and an assessment of risk. As an example, measures applied on large females reduce the risk of not doubling the E/R production, but on the other hand are effective on a longer term (over 50 years).

The final paper looked at Biological Reference points (BRP) for the lobster fishery. Lobster fisheries in Canada have been managed for decades with controls unrelated to assessments of stock status (effort controls, size limits, mandatory discarding of berried females), in contrast to fisheries where harvest limits and other controls are adjusted based on periodic assessments of stock status. In November 1998 a workshop was held in Halifax to consider what reference points might be appropriate for lobster, whether the FRCC's proposed reference point of 5% unfished E/R should be used, and to review current stock assessment techniques for lobster. The paper reviewed the findings of the meeting and presented three classes of BRP that could be considered. Those based on E/R; those based on some measure of a wider size class spread in the population to ensure more multiple spawners and a buffer against changes in recruitment, and finally in the longer term, use of a reference point related to total egg production or egg production per m^2. This last BRP would account better for biological reality, and might be more acceptable to fishers, but would require adding information on abundance (thus potentially higher uncertainty) and more complex models to implement.

SIMULATIONS OF THE IMPACT OF REDUCTIONS IN FISHING EFFORT ON FISHING MORTALITY OF LOBSTER IN THE MAGDALEN ISLANDS USING GLOBAL AND SPATIAL MODELLING

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Introduction

Since the publication of the Fisheries Resource Conservation Council's report on lobster conservation (FRCC, 1995) stating that lobster stocks were overexploited, new conservation measures have been implemented all across Atlantic Canada to increase the E/R production, answering the Minister's request of December 1997 to double the E/R production. In many regions, this objective will be achieved by an increase in minimum legal size. Measures to decrease the exploitation rate and improve stock structure have not yet been directly implemented - neither has there been clear targets defined for their implementation. Reductions in fishing effort are among the measures suggested by FRCC to reduce exploitation rates and the fishing industry has so far made a number of propositions to control fishing effort, such as closing the fishery on Sundays, shortening the season, reducing the number of traps etc. But up until now, no direct assessment of the effect of these measures on the reduction of the exploitation rate have been made.

The objective of this work was 1) to define the relationship between fishing effort and fishing mortality in the Magdalen Islands (Québec) fishery, 2) to build a simple and operational simulation model that will provide a measure of the impacts of temporal changes in fishing effort on fishing mortality and 3) incorporate spatial dynamics of the resource and the fishing fleet in the simulation model.

Material and Methods

The study focused on the Magdalen Islands fishery located off Grande-Entrée on the southern side of the archipelago. Grande-Entrée is the main landing port for lobster where 100 fishers out of a total of 325 land more than 30 % of the total catches of the Islands. The spatio-temporal dynamics of the fishery and the resource in this area are well documented.

To develop our simulation models, we started from the general equation where the fishing mortality is expressed as a function of fishing effort and catchability (Ricker 1980). The basic idea was to investigate the pattern of variability of the catchability coefficient within the fishing season and then use this pattern to simulate the impact of different values of fishing effort on fishing mortality. We investigated this relationship at a daily scale to allow the study of scenarios of reduction of fishing effort at a daily level such as closing on Sundays. The mortality rate for each time interval was estimated from the ratio of catches of the given period to the biomass at the beginning of the same time period. The standing stock at the beginning of the fishing season was derived from an independent estimation of exploitation rate, obtained from modal analysis.

Knowing the fishing mortality and the fishing effort deployed during the same interval, we derived the daily catchability coefficients that were then used for the simulations.

Two simulation models were used. First, we used a global model which assumes that the resource and the fishing effort are distributed homogeneously in the study area. This model was used to simulate changes in the levels of fishing effort and in the temporal allocation of the effort. Secondly, we used a spatial model to simulate changes in the level of fishing effort but also on the spatio-temporal allocation of the effort. The idea was to examine to what extent fishers could compensate for a given reduction in fishing effort by reallocating spatially their effort. The spatial model used here is a simple 2-box model and is an adaptation of a spatial model used by Maury (1998), and Pelletier and Magal (1996). The spatial model is a discretization of the global model into two space units - an inshore and an offshore component separated by the 20 m isobath. The model is computed on a daily basis and the abundance in a given space unit at the beginning of each time period is equal to the abundance at the beginning of the previous period diminished by the fishing mortality and movement outside the unit, and augmented by the animals coming from the other unit. Specific mortality rate in each spatial unit is estimated from the global mortality rate and is based on the concept of surface catchability. Knowing the surface catchability and the local fishing effort we can calculate the mortality rate on each space unit for each time interval. The migration rate is obtained by the difference between the observed catches and the expected catches, given the fishing mortality.

Results and Discussion

Scenarios of reduction in fishing effort were compared to the observed situation in 1995, where 100 fishers using 300 traps each were active 6 days a week (no fishing on Sundays) during a 9-week fishing season. Simulations of reduction of fishing effort included shortening the season to 8 weeks instead of 9 weeks, first, by closing one week earlier and secondly by postponing the opening of the fishing season by one week. The benefits of not fishing on Sundays were evaluated as well as the effects of reducing the number of traps from 300 to 250.

Simulations of the basic pattern, corresponding to the situation observed in 1995, generated cumulative catches of 644 t, corresponding to an exploitation rate of 62 %. These simulated values are similar to the values actually observed of 658 t and an exploitation rate of 64 %.

Reducing the fishing season to 8 weeks, by closing earlier reduced the exploitation rate by 2 %. By postponing the opening of the fishing season by 1 week, exploitation rate was reduced by 6 %. The difference between the two different scenarios of temporal allocation of the fishing effort is accounted for by the seasonal pattern of catchability. In 1995, catchability was high at the beginning of the season, decreased slowly until the 5th week of fishing and then decreased more rapidly until the end of the season. In such a context, opening the fishing season later means that fishermen lose a week of high catchability, unlike closing earlier, when catchability is greatly reduced. The simulation model showed that not fishing on Sundays could reduce the exploitation rate by 4 %. Finally, a reduction of the number of traps from 300 to 250 could reduce the exploitation rate of 7 %, assuming equal efficiency of the remaining traps, compared to initial traps.

Simulation of changes in the spatio-temporal allocation of fishing effort were based on our knowledge of the spatio-temporal dynamics of the fishing fleet. In the Magdalen Islands, we were able to identify 3 types of fishing patterns based on two strategies, one of pursuit and one of interception (Gendron and Archambault 1997). At the beginning of the fishing season about 85% of the fishermen adopt a pursuit strategy that will bring them on the fishing grounds offshore. About 50 % of these fishers will gradually move their fishing effort to the shore as season progresses, joining 15 % of the fishers that have settled inshore from the beginning of the fishing season adopting an inshore interception strategy. A proportion of the fishers (35 %) that went offshore at the beginning of the season will remain there, adopting an offshore interception strategy until the end of the fishing season. Combining these different fishing patterns, we constructed the pattern of fishing effort allocation inshore and offshore for the Grande-Entrée fleet for the 1995 season and incorporated it into the 2-box spatial model.

Simulations were made on 4 modifications of this basic pattern. For the fisher operating with a strategy of pursuit, a reduction of the fishing season by postponing the start of the fishing season by one week will force him to decide whether he will allocate spatially his effort as if the season had opened as usual, assuming that the lobster is still offshore, or whether he will allocate his effort as if he was in week 2 of a usual fishing season, therefore assuming lobster has started to move inshore. We also conducted two additional simulations to see what would happen if the fishermen that fish with an active pursuit strategy would either remain offshore (85 % of the fleet offshore) or would fish inshore among the interception fishers (only 35 % would fish offshore).

Results of the simulations show that changing the pattern of effort allocation in response to a postponing of the opening of the fishing season does not have any visible effect. Starting to move the effort inshore at the beginning of the fishing season reduced catches very marginally, reducing the exploitation rate by 1 % only.

Modifying the pursuit strategy into an offshore or an inshore interception strategy yielded slightly lower catches than the present pattern. Fishing either inshore or offshore yielded on the whole the same catches, giving an exploitation rate of 54 %, a 2 % reduction from the basic pattern. These two simulated strategies yielded lower catches than the one that is currently used. The present allocation of fishing effort made by this group of fishers may be the best one to optimize the catches. The two scenarios examined could not be used by fishers to compensate for imposed reductions in fishing effort. What is interesting in this specific example is that catches were as high staying inshore as by moving up to 20 miles from port, which may not be very cost-effective. Although there is no difference in the total catches between these two scenarios, there could be a difference in the composition of the catch, since a fishery that operates inshore will target the fastest migrants while a fleet operating offshore will mainly fish the animals that tend to migrate inshore later in the season. Characterization of the slow- and fast-migrants might be interesting to assess whether different patterns of spatio-temporal allocation of fishing effort could have a conservation value.

Additional simulation has been made to examine the impact of coming back to a strict inshore interception strategy as it was some 25 years ago. Simulation was made where no effort was allocated offshore. In this case, catches are significantly reduced and exploitation rate drops from 62 % to 46 %. This suggest that not all the lobsters will reach the inshore area before the end of the fishing season.

Propositions made by the Industry to reduce fishing effort have an effect on fishing mortality, although marginal. Temporal allocation of fishing effort is important to consider because of within-season changes in catchability. The present spatio-temporal allocation of the fishing effort (inshore-offshore) by the fishing fleet operating off Grande-Entrée seems to maximize catches. Changes in this allocation will reduce fishing mortality. The pursuit strategy adopted by a majority of fishermen in recent years contributed to an increase in fishing mortality, compared to an inshore interception strategy.

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EXPLOITATION RATE ESTIMATORS OF LOBSTER (*HOMARUS AMERICANUS*) IN SOUTHWESTERN GULF OF ST. LAWRENCE

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Introduction

It is difficult to calculate an exploitation rate for lobster (*Homarus americanus*) due to the complexity of estimating biomass either prior or following a fishery. Trawling on prime lobster grounds consisting of rocky bottom is not possible and the size of each Lobster Fishing Area (LFA) is such that fishing biomass estimation for an entire LFA by SCUBA diving would be too long and costly. Biologists have no other alternatives then to use indirect methods to estimate the exploitation rate. In this study, exploitation rates were calculated using catch-effort and tagging methods. These results were based on previous field observations and computer simulations. The strengths and weaknesses of each method are presented as well as their underlying assumptions.

Definitions and methods

In order to estimate the exploitation rate, it is important to define a study site that covers the entire population under investigation. Although some methods allow for natural mortality, the methods considered in this study assume no natural mortality during the study period.

The mark-recapture method consist of catching and returning tagged commercial size lobsters that were released prior to the fishery season. The proportion of tagged lobsters returned is the estimate of exploitation rate. Although simple, this method is valid only if the following assumptions are respected:

i. there is no tag loss or tag-induced mortality,
ii. all recaptured tagged lobsters are recorded,
iii. tagged lobsters behave independently (no schooling) and are randomly distributed on the fishing ground,
iv. catchability of lobsters is constant during the whole fishing season (or study period),
v. tagged and untagged lobsters have the same behavior (no trap response).

A study is currently taking place to verify hypothesis (i), while hypothesis (iii) can be met if tagged lobster are not released in a single location or if enough time is given for the tagged animals to redistribute. In order for hypothesis (v) to be respected, a method other then a baited trap should be used to capture lobsters for tagging. Indeed, previous studies on other species have indicated a possible tagging effect associated to the capture process, modifying the behavior of the animal. However, taking care of the validity of hypotheses (i), (iii), (iv) and (v) is futile if hypothesis (ii) is not respected and that fishermen do not report tagged animals caught in their traps.

Catch-effort methods are based on the general assumption that the landings are proportional to the effort (number of baited traps hauled). Hence, one unit of effort is assumed to catch a fixed proportion of the population. Thus, a decline in the exploitable biomass will produce a decline in the catch per unit effort (CPUE). The slope of the regression line of CPUE vs cumulative landings is equal to the negative value of the catchability coefficient (-q), and exploitation rate (μ) is estimated by μ=1-exp(-q × total effort for the season). This method requires the following assumptions:

i. all landings are known,

ii. traps do not compete with each other,

iii. sampling is a Poisson process with regard to effort, i.e. P=1-exp(-q × effort) and catchability is constant throughout the fishing season.

Simulations

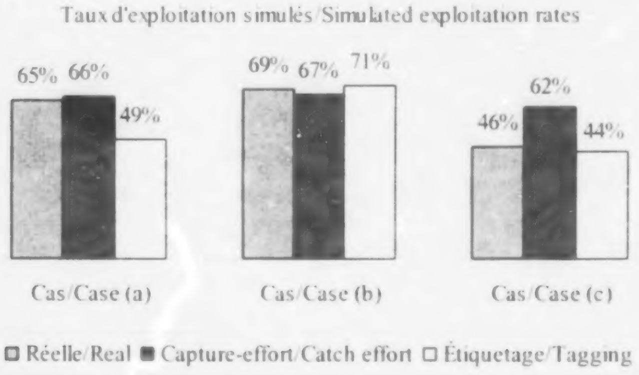
Simulations were made to study the behavior of the estimators when underlying assumptions were violated. A computer generated lobster population was exploited, including a number of tagged lobsters. It was assumed that all recaptured tagged lobsters were reported, there was no tag losses or tag induced mortality, and all landings and effort were known. Three simulation scenarios were considered:

(a) fix catchability during the whole season, annual natural mortality at around 34%,

(b) fix catchability during the whole season, annual natural mortality at around 8%,

(c) gradually decrease by 58% the catchability during the season and lobsters become available to the fishery by 3 successive waves with 65% and 87% available during the 1st and 2nd week, and 100% during the 3rd week and until the end.

Real values represent the value simulated by the computer while catch-effort and tagging represent the values computed using the estimators associated to the methods.



Tagging experiments seem to yield the best results as the estimated values are closer to the real values simulated. Unlike the catch-effort estimator, the tagging estimator is barely affected by a variation in the catchability (case c), variation that occurs in the fishery but with an unknown frequency or scope. Natural mortality has little effect on the catch-effort estimator while the tagging estimator underestimates seriously the exploitation rate (case a). It should be noted that fishermen failing to report the recapture of tagged lobsters is equivalent to mortality of the tagged lobster (since in both cases the information disappears), and affects the estimation directly. For example, if in case (c) only 60% of the recaptured tagged lobsters are reported, estimation of the exploitation rate with the tagging estimator will be 40% lower than the value given in the figure, dropping from 43% to slightly less then 26%. Tag induced mortality also reduces the exploitation rate estimation.

Discussion and Conclusion

Although tagging experiments seem to produce the best estimates of the exploitation rate, previous field observations have detected some potential problems. For instance, lobsters captured by SCUBA diving, tagged and released were recaptured 1.35 times more often then lobsters initially captured by trap. This occurred even though tagging and release of both groups were carried out during the same week, at the same location using the same type of tags. Perhaps the trap-tagged lobsters develop a trap-response? If this is the case, tagged lobsters do not have the same behavior as untagged lobsters and the exploitation rate estimate obtained using tagged lobsters does not apply to the entire population. Furthermore, trap-tagged lobsters released during the first week of the fishery had a higher return rate then lobsters released the previous month of September. Yet, lobsters released in September had to go through 8 weeks of the fishery while May released lobsters were only available to the fishery during 6 weeks. Either lobsters moved in and out of the fishing ground during the off season or there is a high natural mortality. Tagging experiments are costly and represent a major investment of time. However, if fishermen actively participate, it could be a reliable approach.

The catch-effort method is by far easier to manage than tagging experiments as only the participation of a small group of fishermen is required as long as they represent the global behavior of fishermen working in the studied area. Unfortunately, since catch-effort estimators are highly affected by variable catchability, further studies on the catchability of lobsters are required before the method can be used with any certainty.

Another approach that can be used is the change in ratio method (CIR). The CIR consists of comparing the proportion of sub-legal lobsters in the catches at the beginning and at the end of the fishing season. Since commercially exploitable lobsters are permanently removed from the population, the proportion of sub-legal in the catches should increase during the fishing season. This increase could be related to the exploitation rate. The CIR method has recently been applied to the lobster fishery and many questions are still to be answered. For example, knowing the reproductive behavior of sexually mature female lobsters, should we use both males and females or only the male lobsters for the estimation? Are sub-legal and commercial size lobsters equally catchable? How many traps should we sample in order to estimate accurately the exploitation rate? Data collection could take place during sea sampling, or even by the fishermen themselves at a pre-determined date.

Another problem is the representativeness of a single site to evaluate fishery parameters for an entire LFA. The lobster fishery is managed by LFA but unfortunately LFA's do not correspond to natural geographic or biological divisions of the lobster stock and are merely a management tool. Research is taking place using index fishermen, sea sampling and SCUBA diving to identify biological units.

Validation of a method consists of comparing its estimation to the one obtained using fishery independent observations. This is not yet possible for the lobster fishery. However, participation of the southwestern Gulf of St. Lawrence fishermen in our various projects has been good and we believe it is possible to obtain reliable fishery data, but we still need to solve problems associated with the various methods. One should keep in mind that we can not simulate fishermen behavior and their participation remains the essential factor influencing the success of our studies.

A COMPARISON OF DIFFERENT FISHING STRATEGIES ON YIELD AND EGG PRODUCTION OF F AMERICAN LOBSTERS IN NEARSHORE GULF OF MAINE

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Introduction

Different fishing strategies for American lobster, *Homarus americanus*, have evolved in part due to variations in resources, markets and the types of management measures supported by fishers. Two distinct fishing strategies for lobsters exist in the nearshore waters of the Gulf of Maine. In the Canadian portion (LFA 34), the fishing season is limited to a 6-month period (from late November to May), and the number of traps per fisher are limited to 400. In the United States, with a few minor exceptions, there are no regulated seasons, and limits on traps have only recently been adopted. The evolved patterns of fishing in both of these areas show a temporal concentration of effort, and subsequent high proportion of landings over a very short portion of the year. This is, in part, a response to competition amongst fishers. A simulation model, using population dynamics parameters for lobsters, was developed to examine yield and egg production of lobsters under different life history patterns and/or management and harvesting regimes. The model allows multiple time steps during a year to incorporate these differences in life history and fishing tactics on a fine temporal scale. By using this model and assuming the same growth (in both Canadian and US nearshore Gulf of Maine) we have examined the differences in yield and egg production and evaluated differences between the fishing strategies.

Model Overview

Conventional egg production and yield per recruit models are not useful for lobster because age determination is difficult, growth in length is not continuous and the relationship between size and annual egg production is complicated. The model used in this study (Idoine and Rago, in prep) incorporates size-specific annual molt probabilities, assumptions about intermolt duration, molt increments, maturity schedules, fecundities and length-weight relationships. Calculations incorporate interactions between reproduction and growth (e.g. female lobsters suspend molting and growth when they are carrying eggs) and size specific management measures for female lobster (e.g. maximum and minimum size regulations).

In these models for lobsters, it is important to distinguish between "nominal" encounter, capture, retention and fishing mortality rates. The nominal encounter rate is a measure of the rate at which individual lobsters encounter and enter traps. In baseline runs, nominal encounter rates were assumed equal for lobsters of all sizes. Capture rates measure the rate at which individual lobsters enter traps without leaving. Capture rates are less than encounter rates because escape vents allow small lobster to leave traps. Capture rates depend, in part, on size because large lobsters are unable to leave traps through escape vents. Retention rates are based on management regulations and fishery behavior. Legal requirements (minimum and maximum size, prohibition of landing berried lobsters, and v-notch protections) as well as size specific and/or other quality considerations affect release of captured lobsters. Only those lobsters retained are removed from the model population. Encounter and retention parameters in the model can be changed to simulate management measures.

In contrast to nominal encounter and capture rates, fishing mortality rates measure the rate at which lobsters are landed and killed. Fishing mortality rates are usually less (and never greater) than capture rates because management measures (e.g. maximum and minimum size limits, restrictions on landing berried or v-notched females) require that some lobsters caught in traps be released.

Each model run was based on a cohort of male and female lobsters. Growth is modeled using 1 mm size groups. Growth is determined by the interaction of size specific molt interval (the time between molts) and a range of molt increments. The model simulates growth and mortality and keeps track of the number of survivors, number of natural deaths, numbers landed, number mature, number v-notched, number molting and egg production by size group in each time step over the lifetime of the cohort. A monthly time step allows investigation of temporal differences in growth and implementation of management measures.

Biological reference points (e.g. $F_{10\%}$) for lobster were calculated in the EPR and YPR models as abundance weighted averages of fishing mortality over the lifetime of the cohort.

Simulations

The model was run using the two different management scenarios. The major measures are shown below.

Measure	US (Nearshore GOM)	Canada (LFA 34)
Minimum Size	83mm (CL)	83 mm (CL)
Maximum Size	127 mm (CL)	None
Fishing Season	None	6 months (late Nov-May)
Berried Protection	Yes	Yes
V-Notching Rate[1]/Protection	50%/Yes	No/No

[1] rate of v-notching is the proportion of berried females encountered that will be notched.

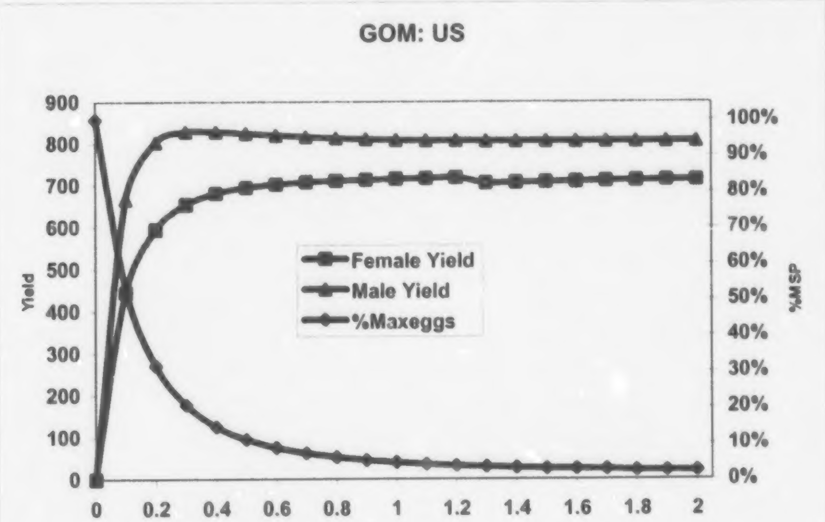
Model runs were made over a range of encounter rates from 0 to 2.0, and yield and egg per recruit estimates were compared for the two management conditions.

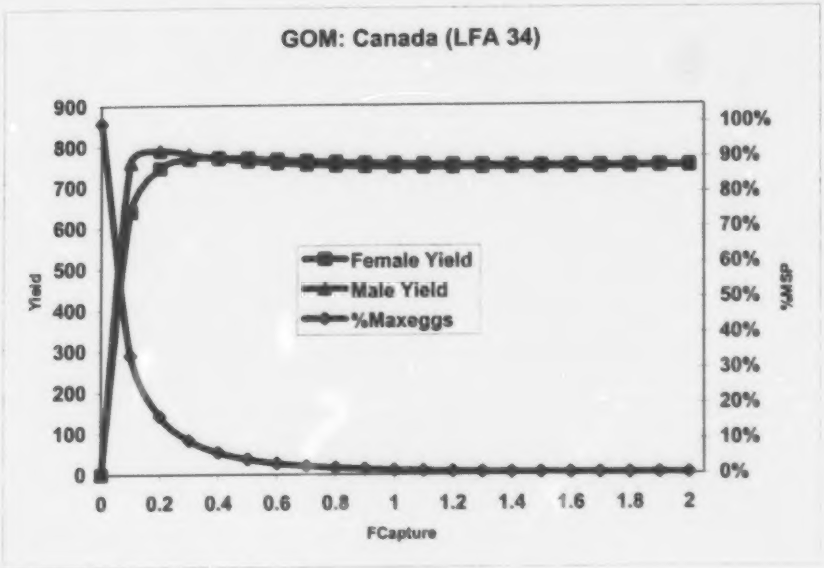
Discussion and Conclusions

The figures below illustrate the outcomes of harvesting under the two strategies. Where there are differences, they are due to what protections are provided to the lobsters, and at what point in their life history. In the US, large animals (> 127 mm CL) of both sexes, and v-notched females are non-harvestable. In Canada's LFA 34, the seasonal restrictions allow more females to extrude their eggs. The "bottom line" of these differences is that the US system, for a given capture rate, allows a gain of some egg production while giving up some in terms of yield. The yield curves demonstrate this well. Under the US scenario, the female yield per recruit is asymptotic. Since females are protected via v-notching and a maximum size, the usual peak at low exploitation is dampened by the unavailability of those animals. The males in the US GOM are also protected by a maximum size, and show a similar damping of maximum yield, but not to the same degree. Under the Canadian LFA 34 system, both sexes yield curves rise to a maximum at low exploitation and then decline. The Canadian protection of egg-bearing females does cause the peak of females to be less pronounced than males, but more than the US females. Total yield (yield from both males and females) though dampened by the female contribution, still show a peak at low exploitation.

What is very clear from this exercise, is that the benefits of both management regimes are better realized at low exploitation. This is simply the manifestation of allowing the lobsters to express those traits that give them protection from harvesting. In the US, this means that at low harvest rates, both male and females are allowed to reach the maximum size (127 mm CL) that ensures their return to the water. In regard to v-notching, a female must become mature to become egg-bearing and thereby have a potential to be v-notched and then protected. With the minimum size of 83 mm CL, only about 2 -5% of the females are mature, and are about 1 molt away from 50% maturity. Additionally, with a year-round fishery, the females that will extrude eggs in a year may be harvested before they do, and thus the potential protection (both from being berried and also possibly notched) is not realized. When the harvesting rate is low, more animals will mature and then be potentially notched and survive to the maximum size. Under the Canadian LFA 34 plan, the only real protection is being egg-bearing, and, as is the case to the south, that protection is greater at low exploitation than at high.

It appears that the most effective way to provide sustainable lobster resources is to attempt to reduce the harvesting rates. The gains in yield, and potential decrease in costs associated with harvesting, should make this an attractive avenue to pursue.




GOM: Canada (LFA 34)
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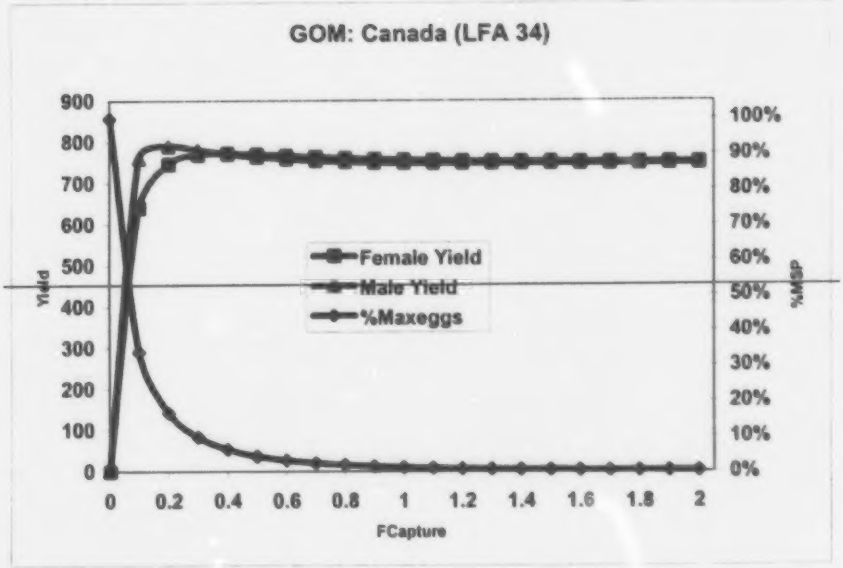
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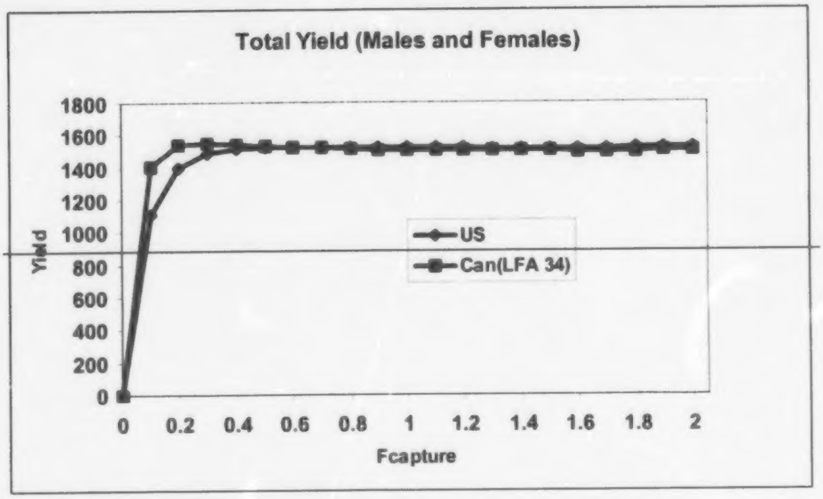
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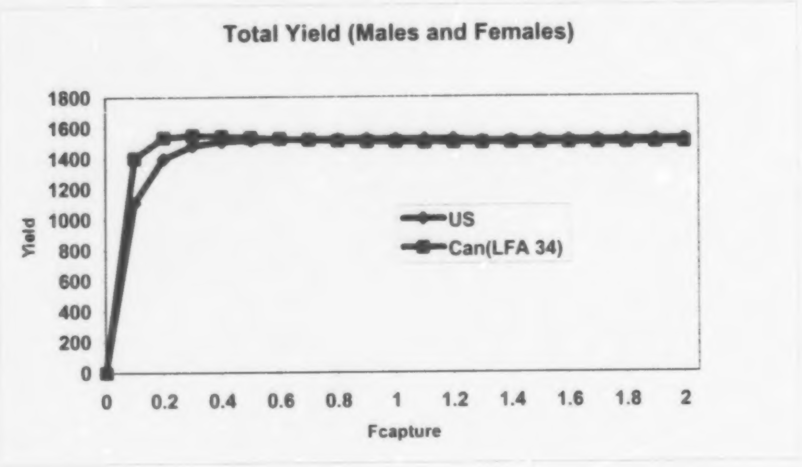
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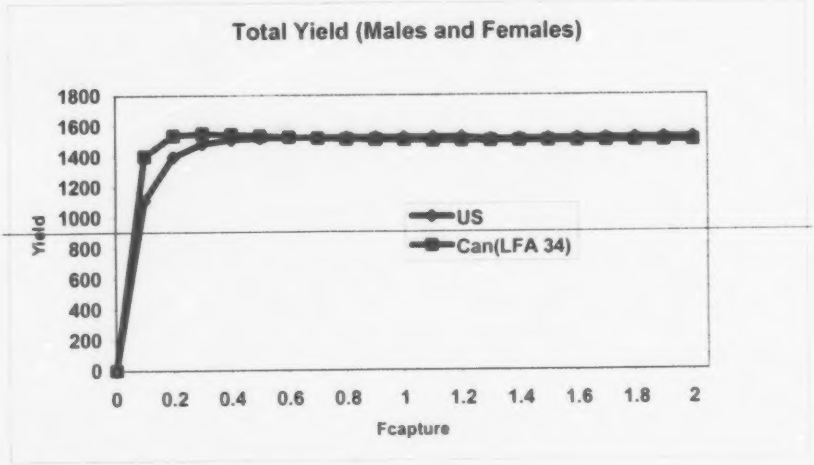
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Can(LFA 34)

LOBSTER EGG PER RECRUIT CALCULATION: INCLUSION OF UNCERTAINTY AND EVALUATION OF THE RISK OF NOT ACHIEVING A MANAGEMENT GOAL

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Introduction

In its report on lobster conservation (FRCC 1995), the Fisheries Resource Conservation Council (FRCC) proposed a new approach to lobster management based on conservation objectives. One of the objectives is to ensure that the level of egg production is sufficient to maintain the resource base over the whole range of environmental conditions. In its recommendations, the FRCC stated that the level of egg production per recruit (E/R) should be increased to the target level of 5% of that of an unfished population, and offered a series of concrete measures that could be taken to reach this target. As a high priority for Science, the FRCC recommended that precise information regarding conservation measures and targets be gathered and better assessments of the actual benefits of such measures be made. Following this recommendation, work was initiated to develop a new formulation of the yield and egg per recruit (E/R) model which would be better adapted for Canadian lobster stocks and which would take into account uncertainty in the input parameters, providing the basis for risk evaluation.

The new model reflects the key biological features of lobster in Atlantic Canada and provides the extra flexibility required to incorporate uncertainty that arises from the natural variability of lobster production processes (growth, natural mortality and recruitment) or from the difficulty in assessing biological parameter values. The model therefore provides a series of values of E/R from which cumulative frequency distributions can be computed to make probabilistic statements leading to risk evaluation. We can define risk as the probability that something bad will happen, the probability being the expression of the uncertainty. For example, one could want to evaluate the risk of not meeting a given management target or one could wish to evaluate the risk of going beyond a given biological reference point, or a threshold that defines a warning zone in which there could be strong chances of stock collapse. In the first case, we would talk of a management risk while in the second case, we would talk of a biological risk.

The objective of the work was to try to apply risk evaluation to the lobster fishery. Lobster management is presently governed by FRCC's recommendations. At the Minister's request, a management target has been set consisting of doubling, within a few years, the E/R production, compared to the 1995 levels. We evaluated the management risk, i.e. the probability of not reaching this management target, given the implementation of a number of different management measures.

Material and Methods

The new model that has been developed is an extension of the Fogarty and Idoine (1988) biological population model for lobster yield and egg production. The new model describes a single sex component at a time, the female requiring far more details than the male. The program calculates the fate of a group of small lobsters of a given initial size distribution, up until their population is reduced to almost zero. Every year, the following sequence of events is repeated. In the case of females for example, the year starts with the fishing season, after which the lobster population divides between those that will spawn and those that won't. The former might molt once before becoming berried while the latter can molt once or twice and remain in the non-berried population until the next fishing season. Meanwhile, the berried population is fished and released and possibly tagged (v-notched), then its eggs hatch, it molts and becomes part of the non-berried population.

The size increment at molt is a function of the premolt size. This function is the same for all life stages. The probability of molting however can be a different function of size for different life stages. For non-spawning lobsters there can be two annual molts leading to a double molt for a fraction of the population. For berried lobsters there is a post hatching molt. Lobsters can also molt prior to extruding eggs. There are two components to natural mortality. The so-called hard shell mortality does not vary with size or age and applies throughout the year. In addition, lobsters that molt are subject to soft shell mortality, a short period of increased vulnerability. The probability of spawning any given year, and the number of eggs produced by a female are a function of the lobster size. Fishing mortality is also a function of size. It is independent of population abundance and does not change from year to year. It can be adjusted by some control measures (overall fishing effort reduction, protection of berried females, protection of large individuals, v-notching and subsequent protection for a given period of time).

The program allows the exploration of different management measures in the context of uncertain information. Each numerical value can in fact be described with its uncertainty by specifying a probability distribution instead of a fixed value. Propagation of the uncertainty to the final estimate of egg and yield per recruit production is done through Monte Carlo simulation, which uses repeatedly a random number generator to pick one value for each parameter based on the parameter's distribution.

Results and Discussion

The model was used to examine the effects of different management measures on the E/R production values for the Magdalen Islands and the Gaspé fisheries. The impact of increase in minimum size, reduction in fishing effort, implementation of a maximum size and v-notching on E/R production were examined. For each management scenario, 100 Monte Carlo iterations were calculated. E/R values were expressed as a ratio of the E/R values calculated before the implementation of the new management measures. Cumulative frequency distribution of the 100 simulated values were used to evaluate the risk of not reaching the given management target.

Results obtained for the Magdalen Islands (south side) show that there is no chance of doubling the E/R production by increasing minimum size from 76 mm to 80 mm. The risk of not reaching the management target is 100 %. By increasing to 82 mm the risk is reduced to 86 % and further down to 24 % with an increase to 84 mm. Combining the increase in minimum size to 82 mm with a reduction in fishing mortality of 10 % or 20 % reduces the risk to 54 % and 12 % respectively. Measures protecting large females (such as complete protection of females larger than 127 mm (jumbos) and 10 % v-notching of berried females reduces the risk of not achieving the management target. Combined with a minimum size of 80 mm and a reduction of fishing mortality of 20 %, the management risk is down to zero.

The model also provides for each scenario, an estimation of the number of years on which the E/R calculation was based. It offers a relative time-frame for the management measures to be 100 % operational, allowing for a comparison between different equally-risky or less risky scenarios. As an example, measures applied on large females reduce the risk of not doubling the E/R production, but on the other hand are effective on a longer term (over 50 years).

Over the last years, there has been increasing interest in quantifying and incorporating uncertainties into fisheries management advice. Quantifying uncertainty provides a better knowledge of the precision and bias of estimates on which advice is based. It also provides an objective appreciation of the reliability of the estimates, avoiding subjective judgements regarding the uncertainties. Expression of uncertainty using probability curves appears useful in a decision-making process because it illustrates the risk associated with a decision. The questions of what level of risk is acceptable, if any, and who should decide on the risk are still open to discussion.

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BIOLOGICAL REFERENCE POINTS FOR LOBSTER A DISCUSSION PAPER - CLAWS SYMPOSIUM

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Lobster fisheries in Canada have been managed for decades with controls unrelated to assessments of stock status (effort controls, size limits, mandatory discarding of berried females), in contrast to fisheries where harvest limits and other controls are adjusted based on periodic assessments of stock status. The FRCC's 1995 report on lobster conservation recommended implementation of a new conservation framework which would include a definition of lobster conservation with related objectives, and a tool kit of measures which could be used to meet conservation objectives and targets. The FRCC report also recommended that an egg production per recruit target of 5% of that for an unfished population be established.

The FRCC recommendation took account of scientific information then available indicating that in most lobster areas of Atlantic Canada egg per recruit values were well below 5% of an unfished population. Lobster assessment science was evolving rapidly at this time, and the FRCC report was based on the first egg per recruit analyses done for Canadian stocks, based on an unmodified US-developed model. At this time, scientists were uncertain of their ability to consistently estimate egg per recruit in an unfished population (because of high uncertainty about fecundity and growth curves in large lobsters), although techniques to estimate current egg per recruit values were considered accurate.

DFO managers and scientists held discussions in fall 1997 on potential measures based on targets and reference points. They recommended adopting an interim target of doubling egg per recruit in each lobster area, pending further scientific assessment of the applicability of the 5% target and ability to assess stock status in relation to this target. This recommendation was adopted by the Minister and announced in December 1997, and was the basis for the four-year conservation strategy for lobsters initiated in early 1998. This strategy was highlighted in the Auditor General's 1999 report on Atlantic shellfish as the only objectives-based conservation strategy in Atlantic shellfish fisheries.

The CLAWS I project identified further work on reference points for lobster as a priority theme. In November 1998 a workshop was held in Halifax to consider what reference points might be appropriate for lobster, whether the FRCC's proposed reference point of 5% unfished egg per recruit should be used, and to review current stock assessment techniques for lobster. Workshop conclusions are as follows.

- Three kinds of reference points should be used to guide lobster conservation:

    1. To implement the FRCC's general recommendation that lobster stock structure should be improved (i.e. that the fishery should be managed to ensure that stocks are based on several year-classes rather than essentially on recruits as at present), a reference point of the type

no more than x% of egg production must be by first spawners

should be considered. Potential benefits: more year-classes in the population, possibly better egg quality from older females, spreading of hatching in time (clutches from older females hatch over longer periods). The most effective ways to meet such a goal would be to reduce fishing mortality, or to institute "refuges" (closed areas, closed size windows, maximum size limits).

2. Percentage of unfished egg per recruit can be effectively used as a reference point for lobster. The workshop thus concurred with the FRCC recommendation that this should be part of the conservation framework. The workshop concluded that egg per recruit in unfished populations can be estimated with reasonable confidence and that by standardising methods for estimating this value, reliable comparative values of the % can be derived.

3. In the longer term, use of a reference point related to egg production per m^2 (similar to a spawning biomass reference point) should be explored. This would account better for biological reality, and might be more acceptable to fishers, but would require adding information on abundance (thus potentially higher uncertainty) and more complex models to implement.

- While reference points based on % of unfished egg per recruit were desirable, it was not possible to state what an appropriate % target would be. The FRCC's recommendation to move to a 5% of unfished egg per recruit was made at a time when analyses suggested that most Canadian lobster stocks were around 1%. Subsequent work with models adapted to Canadian conditions and better input data suggest that current values may be higher than this and above 5% in a few areas, even though there has been no substantive improvement in stock status. The USA overfishing definition is 10% of unfished egg per recruit and this is still considered appropriate there. The workshop concluded that as conservation action based on the Minister's goal of doubling egg per recruit proceeded, analyses could be refined and a well-documented target level might be proposed.

- Reference points should be applied to unit stocks -- application to small areas within unit stocks (LFAs) may be operationally useful but is biologically questionable. Stock boundaries for lobster are still not precisely known and more work on this is needed, for example the larval drift work in CLAWS.

At the time of the workshop, three egg per recruit models were in use in Atlantic Canada (Idoine/Fogarty, Ennis, and Gagnon/Gendron). Their assessments of the effects of various conservation measures on egg per recruit levels were consistent under current fishery conditions but the need was identified for further comparative information on their performance. One CLAWS goal had been to develop a model which could be used across Atlantic Canada but this was shelved because the model developer moved to another position. Comparability of assessments across Atlantic regions remains an issue for discussion.

Biological reference points must be supported by fishermen and fishery managers as well as being biologically meaningful and applicable. The egg per recruit concept has proved difficult for fishermen and managers to accept, despite its desirable biological characteristics (it integrates fishing mortality, fecundity, and size at first capture into an overall measure of stock status, and can be adapted to take account of maximum size limits, V-notching, closed areas, and other management measures). Further work to explain the egg per recruit concept and encourage its adoption, or to find different reference points which are more widely acceptable, is required.

Next steps in the development of conservation measures based on biological objectives and reference points might be:

- discussion between industry, fishery management and science with a view to consensus on appropriate conservation targets and reference points for lobster.
- development of an appropriate egg per recruit target value, if this is accepted by all as an appropriate kind of biological reference point.
- exploration of technical aspects of using size structure and eggs per m^2 as reference points.

Simple measures of exploitation status in lobster stocks exist, and these very simple reference points should be considered in discussions of lobster stock status, pending consensus on more complicated measures. Exploitation rates are extremely high in lobster fisheries, and sizes at first capture remain low in relation to size at maturity. There are few or essentially no lobsters above recruit size in most areas -- a situation which is simply BAD for conservation. Simple measures of exploitation status -- fishing mortality, size at capture relative to size at maturity, and size structure -- should be emphasized and re-emphasized in advice to industry and fishery managers while we continue to improve our knowledge of lobster dynamics and stock status.

SESSION 5: FISHERMEN AND SCIENTISTS

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This session included projects from around Atlantic Canada and Quebec and all of them indicated that close collaboration between fishermen and scientists was not only possible but essential for the improved understanding of this resource. The first project occurred in the Bay of Fundy. In this project, fishermen did the measurements, data entry, and verification of their biological information. Partners included Fundy East Fishermen's Association, Alma Fishermen's Association, and DFO-Science, Maritimes. The project allowed for an improved knowledge of the stock and demonstrated that fishermen were able to collect the biological data, to conduct the data entry and to transfer and share their information on an almost daily basis.

The second project was a survey of fishermen on Magdalen Islands to develop a better understanding of their traditional knowledge and to document a more complete description of fishing effort. This project included the Association des pêcheurs propriétaires des Îles-de-la-Madeleine and DFO-Science, Laurentian Region. This project also indicated that fishermen were quite willing to share information in order to develop an improved collective knowledge of their stocks.

The third type of project was a serial sampling of fisheries from around the Maritimes, including St. George's Bay, Northumberland Strait, Acadian Peninsula and in the waters of Lobster Bay and southwest Nova Scotia. Serial sampling means careful documentation of catches from each trap, which means that fishing effort and location are known exactly. In addition to DFO Science, Gulf Region, this project included partners at three universities: St FofX, UdeM and UQAR and the collaboration of four fishing organizations, MFU, EFF, PEIFA and NSBFA, and DFO Science, Gulf Region. This project indicated that fishermen were willing to share information on location and size of their catch and effort, in order to improve knowledge of the fishery.

The fourth project examined the feasibility of using fishermen-defined protected areas as a way of meeting conservation requirements in the Eastport Peninsula. The partners in this project were the Eastport Lobster Fishermen's Association, MUN, Parks Canada, and DFO Science, Newfoundland Region. The project showed that closed areas could be an effective conservation measure and also demonstrated that local, decision making and community involvement were essential to the success of any project of this type.

BRIDGING THE GULF: EXPANDED INVOLVEMENT OF FISHERMEN IN LOBSTER STOCK ASSESSMENT IN THE GULF OF MAINE

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Background

In the Canadian portion of the Gulf of Maine there is a long record of collaboration between Science and Industry in investigations of various aspects of lobster fishery biology, notably lobster movement. While earlier index fishermen programs have provided localized information on catch per unit of effort trends, two important aspects of lobster fishing activity, the spatial location of catch and effort, and lobster catch size composition, have not been monitored in a comprehensive manner. Additionally, involvement by fishermen in science investigations has typically been through a supporting role, as opposed to responsibility for direct fishery monitoring. Two recent information-gathering projects provide models for development of a framework for expanded Industry involvement in lobster stock assessment.

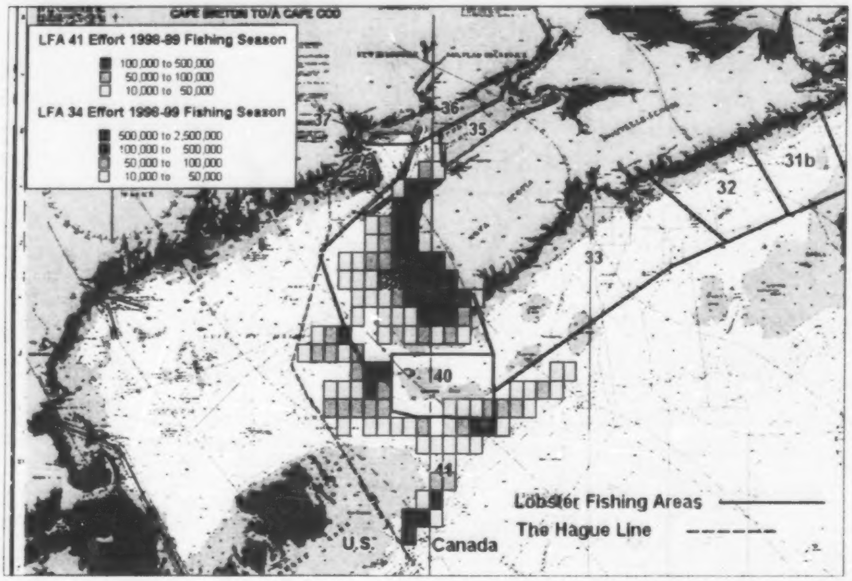
LFA 34 Catch Settlement Reports

Prior to the introduction of a new catch settlement report in November 1998, lobster fishermen in Lobster Fishing Area (LFA) 34, as in other inshore Canadian LFA's, had only to report the weight of their catch, on a daily basis, at the port of landing. In recent years the inshore LFA 34 fishery has expanded into the mid-shore area, out towards the boundary line with the offshore fishery. The only way scientists could assess the relative size of landings from different parts of the LFA was by sporadic at-sea sampling, interview surveys, and interpretation of airborne surveillance information on the location of fishing vessels. This lack of knowledge on the distribution of the catch across the grounds limited assessment of the stock. Ideally, sampling of catch size distribution should be applied to sub-areas of the fishing grounds in relation to the magnitude of fishing effort.

As part of their response to a program to improve the conservation status of Canadian lobster fisheries, LFA 34 fishermen came forward to DFO with a commitment to provide higher-resolution fishing information, specifically catch location, and the number of trap hauls upon which their daily landings were based. As LFA 34 fishermen wished to adopt v-notching as the principal tool in their initial conservation efforts, they also asked that v-notching activity be incorporated into their mandatory catch settlement report. For the fishing season that began in November 1998 LFA 34 fishermen filled in a catch settlement report, reporting catch and effort by reference to a ten-minute grid system. In the catch settlement report there is space on a daily basis for two entries, or two different grids in which fishing activity took place. The grid numbering system was designed for eventual expansion to other fishing areas in the Canadian portion of the Gulf of Maine, such as LFA's 35 – 38 in the Bay of Fundy. The Canadian offshore fishery has been reporting catch by specific location for many years.

From the information provided by LFA 34 lobster fishermen during the 1998-99 lobster season, it has been possible for the first time to comprehensively map the distribution of lobster fishing effort across the inshore and offshore fishing areas (Fig. 1).

Figure 1. Distribution of lobster fishing effort across LFA 34 (Nov. 1998-May 1999) and 41 (Oct 1998-Oct 1999). Effort is reported as the total number of trap hauls per 10-minute grid over the fishing season. Grids in which less than 10,000 trap hauls were reported are not displayed in this data presentation.


CAPE BRETON TO/À CAPE COD
LFA 41 Effort 1998-99 Fishing Season
100,000 to 500,000
50,000 to 100,000
10,000 to 50,000
LFA 34 Effort 1998-99 Fishing Season
500,000 to 2,500,000
100,000 to 500,000
50,000 to 100,000
10,000 to 50,000
36
37
35
31b
32
33
40
41
U.S.
Canada
Lobster Fishing Areas
The Hague Line

LFA 35 Catch Size Monitoring Project

During the 1990's, Science fishery monitoring activities in the Bay of Fundy lobster fisheries had to be reduced, and emphasis was placed on retaining sampling activities at several key fishing ports for which historical data extended back to the 1970's. In recent consultations with lobster fishermen from LFA 35, concerns were raised that Industry had insufficient contemporary information on which to select conservation measures. Subsequent discussions identified the basic elements for an Industry catch size monitoring program: voluntary participation, efficient data recording approach, commitment to timely feedback on results, and eventual incorporation of data into the stock assessment process. Specific data to be obtained were the number of traps being sampled, soak time, lobster size, sex and reproductive condition (occurrence of berried lobsters), total trap hauls and pounds landed on the sampling day, general location and depth range. A column for observations on v-notch lobster abundance was included because two adjacent lobster fishing areas implemented a v-notch conservation program.

Key to the incorporation of this scientific catch monitoring into the fishermen's regular fishing activity was the development of a size gauge and logbook that would permit rapid measurement of lobsters. Whereas scientists use calipers to record individual lobster size to the nearest mm, a decision was made to adopt interval-based size-class measurement. The size interval system selected allowed Science to report back information to Industry in terms of lobster molt size groups (Table 1). The gauge used by the fishermen and the logbooks were printed with the size interval number.

Table 1. Size categories used by fishermen to record lobsters caught in commercial traps

Size Interval on Gauge	Carapace Length Range (mm)	Molt Group
1	< 75	Shorts
2	75-80	Shorts
3	81-87	1
4	88-94	1
5	95-101	2
6	102-108	2
7	109-115	3
8	116-122	3
9	123-129	4
10	130-136	4
11	> 136	5 and greater

The trap-sampling program undertaken by Industry has been successful in providing data at time periods in the fishing season when sea sampling by Science was not practicable. Industry sampling from 1997 to 1999 was conducted in 3 areas in LFA 35. Between 1083 and 1216 trap hauls were sampled during the spring fishery from 1997 to 1999, with 3626 to 4060 lobsters measured. Fall sampling was only done during 1998 and 1999, when 215 to 277 trap hauls were sampled, and 829 to 1732 lobsters measured.

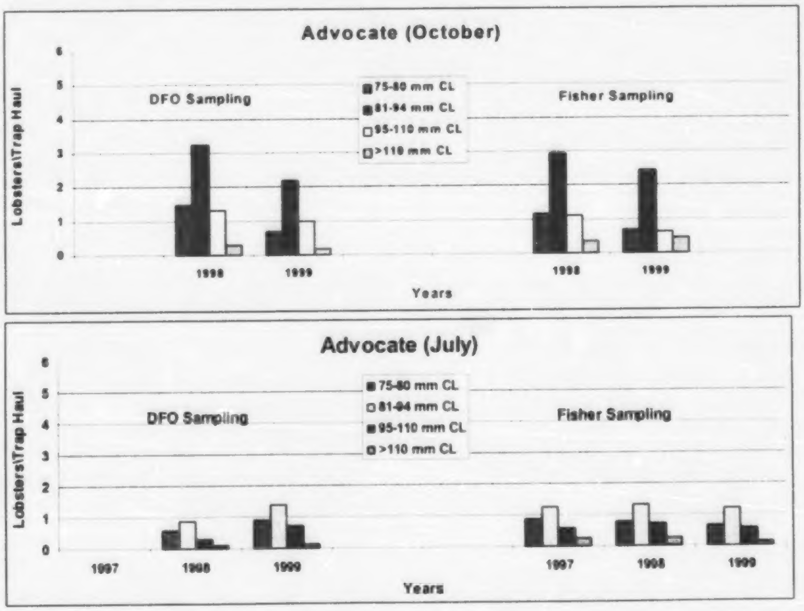


Figure 2. Comparison of Science at-sea fishery sampling, and Industry sampling conducted off Advocate Harbour (one of the three areas sampled), 1997-1999.

Over the three years the observations made by fishermen have been consistent with those obtained by Science (Fig. 2). Among the significant findings from the Industry sampling are the observations of sub-legal sized berried female lobsters (Fig. 3), and the relatively low numbers of lobsters > 123mm CL. The greatest numbers of berried females were measured within the 95-108mm CL size range (Fig. 3).

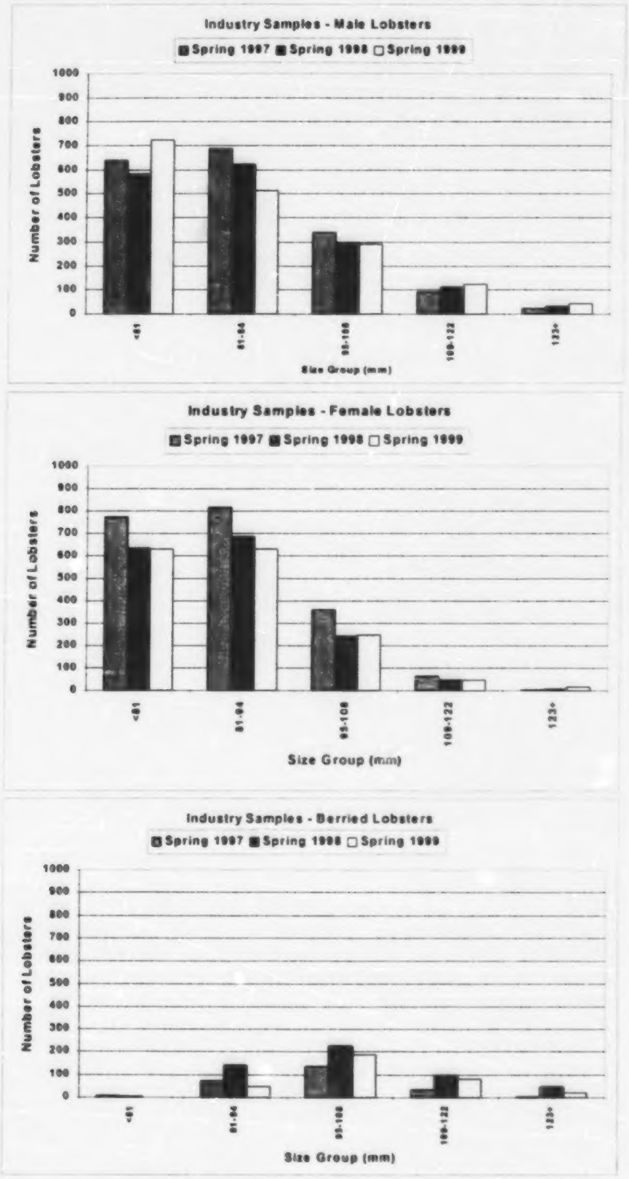


Figure 3. Size distribution by sex and reproductive condition for lobsters sampled by Industry in the upper Bay of Fundy (3 sampling areas combined) during the spring seasons, 1997-1999.

Information Exchange

These two projects placed new demands on Science in terms of expanded information processing responsibilities, and development of new reporting systems. During the 1998/99 lobster fishing season, three in-season reports were provided to the LFA 34 Advisory Committee. During discussion of the information contained in the reports, significant issues were raised on the level of detail that should be reported back to Industry by Science, particularly within the active fishing season. In the LFA 35 catch sampling project, individual catch reports have been provided back to individual fishermen at the end of each season providing detailed data on lobster catch rates, and size composition.

Next Steps

These two Industry monitoring projects are still in development, and there are several key issues that need to be resolved before they can be expanded into an integrated fishery monitoring system. For the Catch and Effort reporting systems, there has to date been only limited success in extending the concept and spatial framework to adjacent fishing areas.

- For LFA's which have more restricted fishing grounds the 10 minute grid system approach may be less useful than the designation of specific fishing grounds, developed in consultation with fishermen, for which to record catch data.
- Fishermen in LFA 34 have raised concerns over the spatial resolution of fishing data that may eventually be released for public access.
- Based on the experience in dealing with the expanded information contained in the new catch settlement reports, there are issues of program resourcing within DFO for information processing in order to provide a timely response.

Based on "proof of concept" through the industry catch size monitoring project in LFA 35, similar programs have been introduced in the Gulf of St. Lawrence, off Nova Scotia, and most recently, in the US Gulf of Maine inshore fishery. Subsequent projects have been introduced as more formal industry-wide proposals, as opposed to the LFA 35 project that was developed through a "grass-roots" approach. Successful development of long-term industry catch sampling program still requires:

- Participation criteria for a long-term program
- Demonstration of utility of new data sources for stock assessment
- Agreement on reporting levels for public access
- Continued development of individual reports for participants
- Resolution of increased data processing demands

The recent experience with Industry driven commercial catch sampling in the Canadian portion of the Gulf of Maine has been very promising, but is now at a crucial stage of development where industry needs to see that the information is used in, and informs the formal lobster stock assessment process. Achieving a comprehensive spatial and temporal overview of commercial catch composition will provide fisheries scientists with key information needed for an eventual spatial model of the lobster fishery. Keyed with the enhanced feedback of information to fishermen, this more participatory environment for lobster stock assessment should bring Science and Industry closer together in their perception of lobster stock status.

SURVEY OF THE TRADITIONAL AND LOCAL KNOWLEDGE OF MAGDALEN ISLANDS (QUÉBEC) LOBSTER FISHERS

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Introduction

The difficulties experienced by the Canadian fishing industry since the late 1980s prompted the industry to request increased involvement in the management and assessment of the status of marine resources. In response, a program of co-operation between biologists and fishers was initiated in 1991 by the Department of Fisheries and Oceans (DFO) Science Branch at the Maurice-Lamontagne Institute (Québec). The objective was to involve fishers in the stock assessment process by promoting the exchange of knowledge between scientists and fishers and emphasizing the complementarity of their knowledge. The program included initiatives to inform fishers about scientific activities and to invite their participation in such activities; in this way, their understanding of the basis of stock assessment was improved. It also included initiatives to document the fishers' own knowledge and make it available to scientists.

In 1995, we developed a project to increase our knowledge of the lobster fishery in the Magdalen Islands (Québec). The development of this project is described in Gendron et al. (2000). The objective was to build a database of information provided by lobster fishers, to make this information available to biologists, and to evaluate the possibility of integrating this type of knowledge into stock status assessments.

Material and Methods

The experimental project was a joint undertaking by fisheries biologists and anthropologists and involved semi-structured interviews of 40 fishers. Information was gathered on the four following themes: a) the recent evolution of fishing practices of Magdalen Islands lobster fishers; b) their empirical knowledge of lobster biology including the lobsters' spatial distribution, behaviour, life cycle, habitat, and interactions with other species; c) fishers' social organisation, local marine tenure and internal rules governing the sharing and access to the fishing grounds, as well as their perceptions of DFO's stock assessment (scientists) and fishery management (managers and officers); and, d) their perceptions and interpretations of large-scale changes in lobster abundance as well as in the environment, either recent or past, including observations made by their father and grandfathers. An ethnographic approach was used to frame fishers' knowledge in its cultural and social context. The resulting information was classified as 220 variables in a Microsoft Access database.

Up until now, we have focused our analysis mainly on the evolution of the fishing practices. The database on fishing practices (50 variables) was consulted by biologists and information was extracted and then used in the assessment of lobster stock status in 1996. Fishing effort is controlled in Québec; and in the Magdalen Islands, the number of licenses and the number of traps (300) per license, along with the length of the fishing season (9 weeks), have not changed since 1973. In addition, there is a minimum legal size and it is prohibited to land egg-bearing females. Despite awareness that various components of fishing effort in the Magdalen Islands had changed in recent decades and harvesting efficiency had increased, no attempt had been made to describe the changes. Fishers were thus questioned on how their harvesting practices had changed since 1973. More precisely, we sought to quantify changes in the fishing equipment (vessels, navigation apparatus, sounders, traps), as well as to quantitatively and qualitatively document changes in fishing practices (traps and lines) and strategies. The details of the changes made to fishing equipment and fishing practices over the past 20 years as reported by the fishers are described in Gendron and Archambault (1997).

Results and Discussion

We learned that the Magdalen Islands fishers have increased their fishing capacity substantially since 1975. Modifications made to vessels since the early 1980s have enhanced their power, speed, stability, and capacity for trap transportation. As vessel size increased, navigation tools (positioning and sounding devices) were also being improved which freed the fishers from the need to use visual reference points. Fishers began to move further offshore while decreasing the time it takes to locate fishing sites and retrieve traps. Colour sounders have permitted the discovery of new lobster grounds on small reefs situated between traditionally harvested areas. The combined use of the colour sounder and a positioning system provides improved control over the deployment of traps on reefs, and strategic placement helps to ensure better catches.

Over the past two decades, every minute detail of trap design has been examined by fishers. Traps used at present are very different and more efficient from those employed in the 1970s. Fishers also modified their fishing strategy, shifting from interception to deliberate pursuit of the species. They are now able to go after lobster wherever they are; for example, they exploit offshore lobster grounds early in the season rather than waiting for lobster to reach traps set near the coast, and they follow the lobsters' movements during the season. This pursuit strategy probably results in higher catches since, in the past, not all lobster would reach the interception site before the end of the season (Gendron and Brêthes 2000). The technological changes described above have occurred rapidly as a result of the competitive nature of this fishery. The degree of competition varies, however, depending on such factors as the way the fishing grounds are shared.

All this information from fishers on the evolution of fishing equipment and practices over the past 20 years was taken into consideration during the 1996 assessment of the lobster stock status. Two aspects of the stock assessment could be better interpreted or understood within the context provided by the new information. First, this new information supported the contention that the Magdalen Islands lobster stock has been subjected to increased fishing pressure over the past 10 or 15 years. Secondly, the information on changes in fishing efficiency provided evidence that the observed upward trend in the early-season catch per unit of effort (CPUE) since the late 1980s reflected not only the available biomass, but also the effectiveness of the pursuit strategy, i.e. the greater ability of the fishers to locate and harvest concentrations of lobsters at the beginning of the season. The increase in CPUEs also reflects the improved performance of the traps, including their capacity to hold more individuals, reduced selectivity in terms of lobster size, and, above all, the strategic way they are now positioned on the fishing grounds.

In addition to providing solid contextual information for the stock assessment exercise, the information on changes in fishing efficiency highlighted two important processes that need to be considered very closely in the future. First, an increase in fishing efficiency had occurred despite tight regulation of fishing effort. Secondly, the recognition that it will never be possible to prevent fishers from becoming more efficient. This highlights the importance of implementing a procedure that will allow biologists and also managers to continuously document and closely monitor innovations related to fishing practices and strategies. Also, it raises the question of the effectiveness of attempting to reduce fishing mortality by reducing fishing effort. A fisher will be able to partly compensate for reductions in fishing effort by increasing fishing efficiency. Thus, management measures designed to achieve conservation goals should take the continuous improvement of fishing efficiency into account.

Following the stock assessment exercise, the results on stock status were presented to all Magdalen Islands fishers. The incorporation of the information given to us by fishers increased the credibility of the scientific conclusions concerning the harvesting of lobster populations. It caused fishers to be more concerned about the level of exploitation of the Magdalen Islands lobster populations and about their high fishing efficiency: they could better acknowledge the fact that the high landings and catch rates were not exclusively a product of an increase in lobster biomass. The exercise provided an opportunity for scientists and fishers to adopt the same viewpoint about stock status, from which both parties can build the future of lobster conservation. This element contributed to the successful implementation of stronger conservation measures, to which fishers were very receptive.

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SURVEY OF LOBSTER FISHERS IN ST. GEORGE'S BAY, NOVA SCOTIA

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Catch rates are used in the lobster fishery to calculate exploitation rates and exploitable biomass but have been criticized as being a poor index of stock abundance. The main difficulty is that current methods use aggregate catch and effort information where the true sources of variation are unknown. The data presented in this talk were collected on four different fishing boats in LFA 26A and 26B. The data were collected on a very fine scale and included weather conditions, number of traps hauled, number of traps per buoy, position of each buoy, depth of each buoy, soak time, bottom temperature, catch characteristics and bycatch. Preliminary analysis shows differences in the abundance of undersized and canner lobster and differences in the number of lobsters missing or regenerating claws in St. George's Bay.

This information is part of a larger project being completed at different locations around the Maritimes. With this data set DFO will be able to examine factors that may influence catch rates, including those controlled by the fisher, such as number of traps per trawl, type of trap, density of traps, depth and bait, and those that cannot be controlled such as water temperature and size, sex and maturity of catch. These will be compared to conventional estimates of catch rate.

SPATIAL AND TEMPORAL ANALYSIS OF CATCH AND EFFORT DATA IN THE MARITIME'S LOBSTER (*HOMARUS AMERICANUS*) FISHERY

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The lobster fishery provides a living for hundreds of communities along the Canadian Atlantic coast. The pursuit of this economic activity totally depends on the health of the resource. In this context, one can easily understand the importance of an adequate assessment. An important part of this assessment is still done today by the analysis of the catch per unit of effort (CPUE) data, which is used as an index of abundance. It is assumed that the fishing mortality is proportional to the amount of effort deployed in the fishery. In other words, a two-fold increase in the density of lobster on the bottom would produce a similar increase in CPUE. Likewise, an increase in effort is expected to induce a proportional increase in mortality. Unfortunately the reality is not that simple and the question today is not whether the CPUE is a reflection of the real abundance but what is the relation between CPUE and abundance. To answer this question one must be aware of the elements that may affect not only the catch but also the effort. A proper definition of the unit of effort then becomes crucial.

The objective of this project is to analyse the catch and effort data provided by sea sampling at different spatial and time scale and hence to study the relationship between space, the number of traps per lines, the time of the season and yields.

From a preliminary analysis of the data that were collected from widely separated fishing zones during 1998-1999, it is clear that in some cases, the area fished, the number of traps per line and the time of the year have an influence on the catch and catch rate.

FISHERMEN INVOLVEMENT IN LOBSTER FISHERY MANAGEMENT IN EASTPORT, NEWFOUNDLAND

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The Eastport Peninsula Lobster Protection Committee, involving some 50 fishermen from seven neighbouring communities, was formed in 1995. It was a response to heightened concerns about overfishing the resource associated with landings declines and effort increases following the northern cod moratorium. Timing coincided with the FRCC review of lobster conservation in Atlantic Canada and some of the key organizers had been involved in consultations that were part of that review.

Initially, through peer pressure exerted through the Committee, the focus was to achieve compliance with existing regulations and to promote voluntary v-notching of egg-bearing females as one means of addressing long-term conservation concerns associated with a low level of egg production.

In order to acquire a meaningful degree of local control over the management of the lobster resource in their area, the Committee entered into a Memorandum of Understanding (MOU) with the Department of Fisheries and Oceans. Starting in 1997, this established a boundary around the Eastport Peninsula that restricted Eastport fishers to within their traditional lobster fishing grounds but also eliminated the possibility of outside encroachment. This made Bonavista Bay the only Lobster Fishing Area (LFA) with a within-area restriction on licence-holder mobility. As another conservation measure, the MOU also established two areas within the Eastport boundary that were closed to lobster fishing. These were recently upgraded to complete no-harvest areas and the Committee has also been working towards obtaining formal MPA status.

Initiatives by the Committee also led to a multi-agency cooperative arrangement to establish comprehensive fishery monitoring with logbooks and at-sea sampling and to conduct research focused on evaluating the closed areas as a lobster conservation tool and establishing baseline indices of larval and juvenile abundance.

The local school is involved in the processing and preliminary analysis of fishery data in an effort to encourage greater ongoing community involvement. The intention is to also directly involve stakeholders in the interpretation of results utilizing their knowledge of year to year changes in local conditions and TEK. Their representatives would then be better prepared to participate in the advisory/consultative process leading to resource management decision making.

The Committee is presently seeking funding to establish a Lobster Conservation Resource Centre at the school. This is intended to be a multi-faceted facility available to the entire community providing access to information technology and creating ongoing opportunities for education, professional and economic development, fisheries research, resource conservation and stewardship.

MAPPING THE SEA BED OFF THE MAGDALEN ISLANDS (QUÉBEC) WITH A SIMRAD EM-1000 MULTIBEAM ECHOSOUNDER: A TOOL FOR STUDIES ON LOBSTER

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Mapping the seabed off the Magdalen Islands (Québec) was initiated in 1995 to support studies on lobster requiring some knowledge of the sea bottom. The objective is to produce detailed and high-resolution maps of the bathymetry and reflectivity of the grounds located on the northeast side of the Magdalen Islands, that support lobster populations and fishing activities.

Mapping of the seabed is done using the multibeam echosounder Simrad EM-1000 of the Canadian Hydrographic service (CHS). The EM-1000 is equipped with a transducer allowing the formation of 60 beams spaced out at 2.50°, giving an opening of 150°. The sounder works at a frequency of 95 kHz and can operate at depths varying from 5-800 metres. The swath, a width attaining a maximum of 7.4 times the water depth, allows for total bottom coverage. The system EM-1000 is perfected to supply not only bathymetric data, but also information on acoustical reflectivity of the seabed, leading to the production of sonar images. The EM-1000 is installed on the Frederick G. Creed, a 20.42 metres aluminium ship using the SWATH technology (Small Waterplace Area Twin Hull). The Frederick G. Creed can operate in relatively shallow waters, is very stable and can move rapidly (up to 18 knots).

The area surveyed is located on the northeast side of the Magdalen Islands. This area represents one of the main lobster fishing grounds of the archipelago. Approximately one third of the lobster fishing fleet (100 boats out of 325) operates on these grounds that extend up to 20 miles offshore. Mapping of the area began in 1995 and was continued in 1996, 1998 and 1999. Up until now, approximately 600 square kilometres of the area has been mapped. Each year, maps of bottom relief, reflectivity and bathymetry were produced. Data processing was done the first two years by the Ocean mapping group of the University of New Brunswick and then by the CHS of the Laurentian Region. In 2000 the CHS produced the three type of maps for all four years combined.

In 1996 and 1999, sediment sampling and underwater photography were used to validate the reflectivity images and clearly characterise soft (mud, sand) and rocky (gravel, pebbles, boulders and bedrock) grounds.

The maps produced have so far been useful in a number of research projects. Three of these projects are explained below.

1. Lobster abundance survey using a Nephrops trawl – *soft bottoms.*

A trawl survey was initiated in 1995 to obtain indices of lobster abundance – recruits and prerecruits – and help forecast recruitment to the fishery one to three years in advance (Gendron et al. 2000). The survey is done using a Nephrops bottom trawl. Originally, a systematic sampling design was used to determine the location of the sampling stations. However, because the use of the trawl is restricted to soft bottoms, a number of stations had to be relocated, from hard bottoms to adjacent soft bottoms. This relocation was done based on the reflectivity and the relief maps. Maps were therefore very useful to precisely locate and avoid untrawlable bottoms. The maps also proved useful in the data analysis, for example to examine the importance of the proximity of rocky areas on lobster abundance. Maps will also be used in the near future to evaluate the proportion of total lobster habitat that can be surveyed with the trawl, increasing the precision of lobster abundance estimates.

2. Lobster abundance surveys using Scuba diving - *prime rocky habitats*

Parallel to the trawl survey, we have also initiated assessments of lobster abundance on their prime rocky habitats using SCUBA diving. We were interested in examining changes in lobster abundance as a function of the distance from rocky areas (reefs). We relied on the reflectivity and relief maps for the planning of a survey on one specific reef in 1999. The reef was easily located and delineated. It was then possible with the high-resolution maps to properly define 100-metre transect lines on the reef and at given distances from the reef (50, 200 and 600 metres). Exact positions of the sampling sites were then extracted from the maps, reducing significantly uncertainty and on-site searching time for the proper substrates.

3. Spatio-temporal distribution of fishing effort and lobster abundance.

Using a GIS mapping tool software (MapInfo) we are in the process of mapping fishing effort and catch rates from our commercial at-sea sampling programs. This will allow a better understanding of the spatio-temporal variability of the fishing activity and lobster abundance, as the fishing season progresses. This will help for a better interpretation of catch rates, and the recognition of fishing strategies. It will provide relevant information for the management of fishing effort.

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Gendron, L., H. Bourdages and G. Savard. 2000. Development of an abundance index for lobster (*Homarus americanus*) in the Magdalen Islands (Québec) from a trawl survey. *This symposium*.

DEVELOPMENT OF AN ABUNDANCE INDEX FOR LOBSTER (*HOMARUS AMERICANUS*) IN THE MAGDALEN ISLANDS (QUÉBEC) FROM A TRAWL SURVEY

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Introduction

A trawl survey was initiated in the Magdalen Islands (Québec) to obtain indices of lobster (*Homarus americanus*) abundance – recruits and prerecruits – and help forecast recruitment to the fishery one to three years in advance. Preliminary trials made in 1994 with a Nephrops trawl showed that this type of gear was less selective than traps with respect to size. Lobsters down to 55 mm carapace size (two to three molts away from commercial size) were readily caught by the trawl. The use of the Nephrops tawl is however restricted to soft bottoms and therefore is not appropriate to catch cryptic or emergent juveniles that are dependant or remain in the vicinity of shelter-providing habitats. Vagile juveniles, adolescents and adults that forage and disperse more widely are more vulnerable to the trawl.

We hypothesize that the fraction of the population present on soft bottoms in the fall and caught with the trawl gives an indication of the overall abundance of lobster in the area, allowing for predictions of the recruitment to the fishery. This hypothesis may be valid only for the Magdalen Islands where soft bottoms represent more than 80% of the area. In 1995, a sampling design was developed and annual surveys have been carried out since. Data on the abundance and distribution of lobster of different size groups are presented for 1995 to 1999.

Material and Methods

This annual survey has been conducted on the northeast side of the Magdalen Islands (Québec), off Grande-Entrée which is the main landing wharf of the archipelago, accounting for one third of total landings (≈ 600 t vs 1800 t). The survey has been carried out in September after the molting period, between 7 and 35 meters, while lobsters are mainly concentrated inshore. Each year, 38-42 fixed-stations were surveyed and two 10-minutes tows 100-200 m apart were done at most of the stations. Swept area was calculated based on exact distance of the tow and trawl opening (Scanmar). Location of sampling stations was done following a systematic sampling design, modified to avoid untrawlable areas, based on the Simrad EM-1000 images of the sea bed (Gendron and Sanfaçon, 2000). Each year, up to 8000 lobsters were caught, ranging in size between 23 and 170 mm carapace length (CL).

Lobsters (males and females grouped together) were separated into molt groups based on previous growth data. Four groups were defined: 1) the recruits to the fishery for the coming year, i.e. lobsters ≥ 76 mm (COM), 2) the pre-recruits one molt from commercial size i.e. 67-75 mm (PR1), 3) the pre-recruits approximately two molts from commercial size, i.e. 55-66 mm (PR2), and 4) the juvenile lobsters < 55 mm (JUV). The lower limit of the COM category was increased annually by 1 mm from 1997 to 1999 to take into account the increase in minimum legal size to 78, 79 and 80 mm for the 1998, 1999 and 2000 fishing seasons. For each tow, lobster density (number/1000 m^2) was estimated for each size group. This abundance index is relative and refers to a trawlable biomass. Mean annual lobster densities and variance were estimated using geostatistics. Variograms were calculated with GS+ software. Means and variances were calculated using EVA2. Point kriging with GS+ was used to map lobster concentrations.

Results and Discussion

Size frequency distributions of lobsters (males + females) from 1995 to 1999 ranged from 35 mm to 160 mm. The majority of lobsters (>90 %) were between 55 and 95 mm in size. Large lobsters (jumbos, ≥ 127 mm CL) were rare in the trawl. Catches consisted of males and females in the same proportions except for larger sizes (≥ 85 mm) (M:F = 1.8:1). The proportion of berried females was low during the 5 years of the survey (maximum of 2.5 %). During the study period, the abundance of lobsters of commercial size varied from 4.6 to 7.1 lobster/1000 m^2. The highest density was observed in 1995. Abundance fluctuated without any trend in the following years. There is a high correlation – although not significant - between the abundance of commercial size lobsters in the trawl survey and landings the following year. The data series is still too short for its predictive value to be assessed.

In the last two years of the survey, there has been a downward trend in the abundance of lobster PR1 and PR2 and since 1997 for the JUV category. It will be important to follow this trend to see if it is maintained as lobsters grow to commercial size. The survey could prove to be a relevant tool for mid-term forecasts of recruitment to the fishery. The JUV category (< 55 mm CL) corresponds likely to lobsters approximately 4 years old. The low abundance of the JUV in 1999 could reflect the weakness of the 1995 cohort. Indeed, very low lobster benthic settlement was observed in 1995 at a monitoring site in the Magdalen Islands (Sainte-Marie et al., 2000).

Density contours were prepared by kriging and show a gradient in the abundance of lobsters of commercial size (COM), with a decrease in the offshore direction, as depth increases and water temperature decreases. At this time of the year, lobsters are absent in waters less than 4°C and in reduced numbers in waters below 10°C. The largest concentrations of commercial-size lobsters appear to show spatial coherence from year to year. Pre-recruit (PR2) and juvenile (JUV) lobsters tend to concentrate at lower depths and closer to rocky habitats.

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Gendron, L. and R. Sanfaçon. 2000. Mapping the sea bed off the Magdalen Islands (Québec) with a Simrad EM-1000 multibeam echosounder : a tool for studies on lobster. *This symposium.*

Sainte-Marie, B., D. Chabot, F. Hazel and L. Gendron 2000. Preliminary analysis of settlement intensity and growth of juvenile lobster in the shallows of Baie de Plaisance, Magdalen Islands. *This symposium.*

MODELLING NEAR-SURFACE CIRCULATION OFF SOUTHWEST NOVA SCOTIA

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As part of CLAWS I, a project was undertaken to model the drift of lobster larvae in the Canadian portion of the Gulf of Maine as a means of determining potential sources of lobster larvae for the inshore areas off southwestern Nova Scotia. This poster presents the summertime circulation flow fields from the model.

The circulation patterns were obtained from an existing finite-element numerical model that is forced by winds and upstream sea level elevations. It is initialized with the mean summer density field but the densities are allowed to adjust to be dynamically consistent with the calculated flow field. Within CLAWS I, the model was improved to include more realistic physics in the very near surface layer (upper few meters). The main features of the near-surface circulation from the model under mean wind conditions are consistent with observed flows. This includes the clockwise gyres on Georges and Browns Banks, an anticlockwise circulation in the central Gulf of Maine, a southwestward flow along the coast of Maine and an intensified northward flow over Lurcher Shoals. Good agreement was also obtained between the model flow fields and the tracks of drift buoys released during CLAWS I in the vicinity of Browns Bank.

To explore potential drift patterns, model particles were released at different depth levels from northern Georges Bank, southwestern Browns Bank, German Bank and Lobster Bay and advected by the model currents for periods of up to 60 days. In the top few meters of the ocean, currents are strongly forced by the wind whereas the pressure gradients associated with the density field, the tides and bottom friction are the main forces driving the residual currents deeper in the water column. Under the long-term mean southwesterly winds, near-surface currents tend to be eastward except near the coast. Below the wind-induced Ekman layer (10 m), the currents on Georges Bank form the well-known clockwise gyre. Most particles released on southwestern flank of Browns Bank at 10 m flow into and eventually around the Gulf of Maine, as do those on German Bank. The particles released in Lobster Bay generally remain in the Bay or become distributed along the coast from Cape Sable to St. Mary's Bay. The near surface currents vary greatly, depending upon the strength and direction of the winds used to force the model.

LONG-TERM MONITORING OF LOBSTER SPAWNING AND NURSERY AREAS IN THE BAY OF FUNDY, 1989–1999

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Introduction

From first harvest in 1979, the Atlantic salmon aquaculture industry in southwestern New Brunswick grew to a production of 18,600 t in 1997 from 80 growout sites (Chang 1998). A synoptic, diving-based, field survey was undertaken during the period 1989 - 1993 to document sensitive lobster fishery areas in the Fundy Isles region of the Bay of Fundy. During these studies between 13 and 27 coastal locations were visited annually, either adjacent to existing sites, or at sites then proposed for future development (Fig. 1).

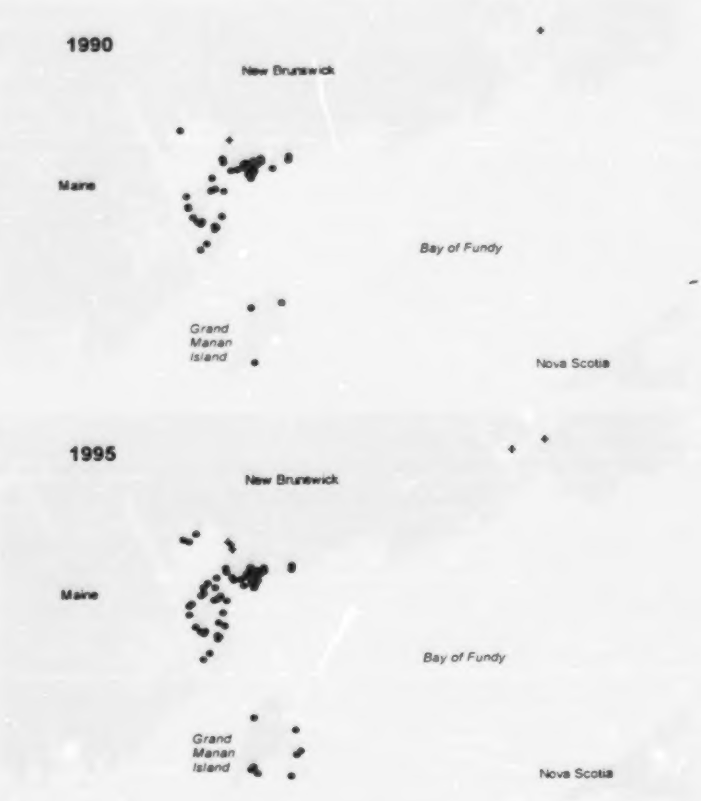
1990
New Brunswick
Maine
Bay of Fundy
Grand Manan Island
Nova Scotia
1995
New Brunswick
Maine
Bay of Fundy
Grand Manan Island
Nova Scotia

Fig.1. Marine Atlantic salmon aquaculture sites in southwestern New Brunswick, 1990 and 1995 (from Chang 1998).

Methods

For the synoptic survey (Lawton 1993) lobsters were sampled by divers searching along 150m x 2m belt transects set across a range of bottom types and depths from 20 m to the shallow subtidal. Between 40 and 88 transects were sampled annually. Additional data on relative lobster abundance was obtained from timed collection dives (17 to 38 annually). Over 5000 lobsters were sampled using these hand-collection approaches.

Two general types of lobster habitat were considered to be sensitive to coastal zone development impact: **nursery areas** where lobsters settle to the seabed and spend their early benthic period on a year-round basis, and **spawning areas** where adult lobsters move into shallow coastal sites on a seasonal basis to complete reproductive functions.

Following the synoptic survey, two key sites, Beaver Harbour (a nursery area) and Flagg Cove (a spawning area) have been sampled on an annual basis to yield time series on lobster habitat use (Fig. 2).

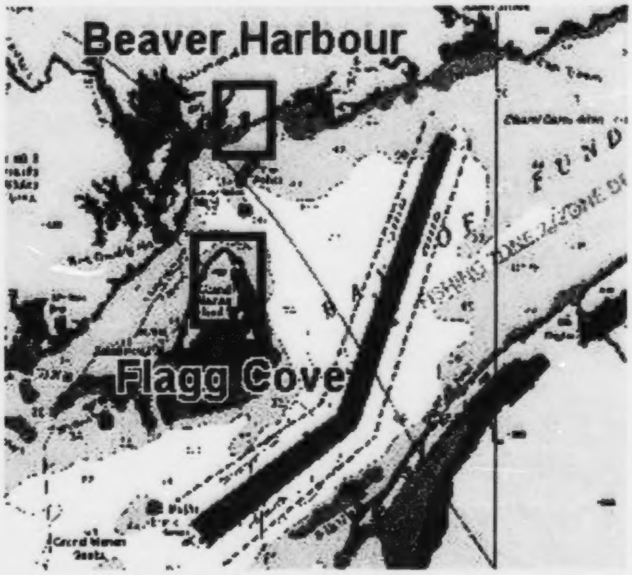

Fig. 2. Beaver Harbour and Flagg Cove Sites.

Beaver Harbour study site

To properly determine nursery area function and to intercept lobsters after settlement (approx. 5 mm carapace length, CL) air-lift suction sampling approaches were adopted in 1990, following earlier research by U.S. scientists (Wahle and Steneck 1991). Over the period 1991 to 1999 between 2 and 12 specific sites in the Beaver Harbour area have been sampled annually. At each sampling site a minimum of twelve 0.25 m^2 quadrats were sampled in complex cobble-boulder habitats between 5 to 15 m water depth, grouped into West Harbor and East Harbour locations.

Settlement has been recorded annually (Fig. 3) and these settlement densities are comparable to those recorded in similar cobble-boulder habitats in mid-coast Maine study sites by U.S. researchers. The low settlement recorded in 1996 is consistent with the pattern seen in coastal Maine in that year.

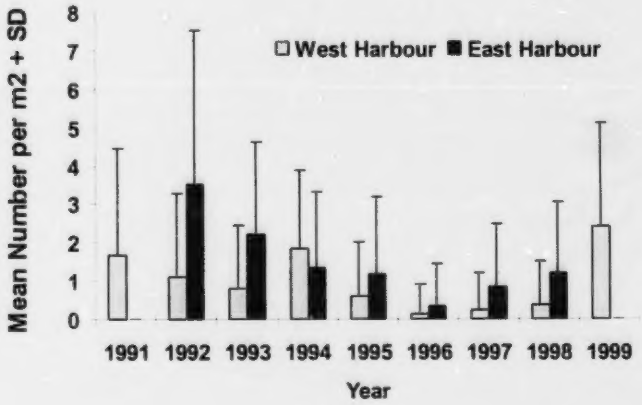

Fig. 3. Annual settlement density (lobsters < 13mm CL) at Beaver Harbour

The suction sampling approach effectively samples lobsters from settlement to approx. 50 mm CL (Fig. 4).

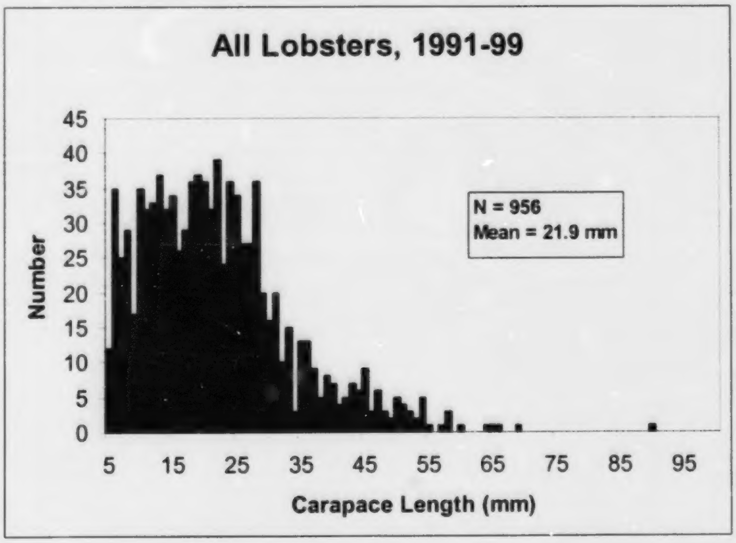

Fig. 4. Lobster size distribution from air-lift suction sampling at Beaver Harbour (1991-1999).

Flagg Cove Study Site

Use of shallow water locations around Grand Manan as seasonal spawning sites was first reported from studies in the early 1980's which used trap-based and diver sampling approaches to document sex ratios, size structure, and lobster relative distribution (e.g. Campbell 1990). A sex ratio highly skewed towards female lobsters (of which most were berried) was discovered among primarily adult assemblages of lobsters occupying sandy bottom areas of coves in the vicinity of the port of North Head.

Subsequently, the approval of a salmon aquaculture site in Flagg Cove (immediately adjacent to the port of North Head) in 1989 prompted a new series of studies to monitor this lobster habitat use and advise on potential impacts.

Divers sampled belt transects (300 m x 2) along a series of sites within the cove. Depths ranged from 20 m to <5 m water depth. During 1990, surveys were conducted monthly from June to October, then on an annual basis in September only of each year up to 1999.

During the period the aquaculture site was in operation lobster distribution shifted away from locations which had historically been documented as high density sites. In years subsequent to site removal, the historical pattern of lobster habitat use seen historically in September has been re-established (Fig. 5).

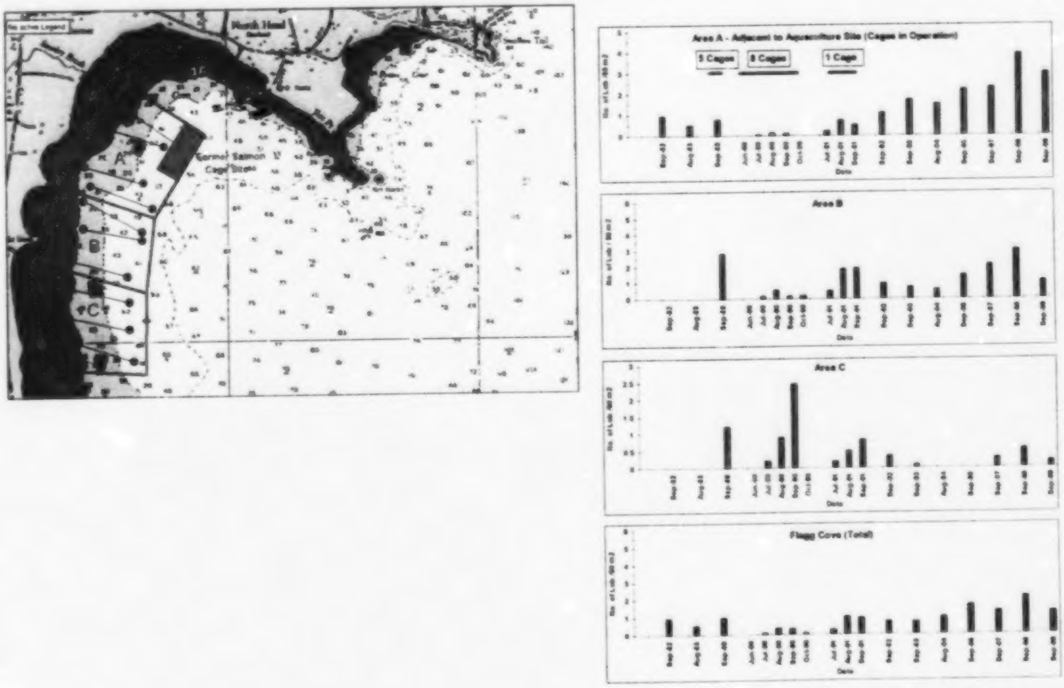

Fig. 5. Changes in Lobster Distribution observed at Flagg Cove.

Most recently, we have noted the presence of sub-legal lobsters at our sampling sites (Fig. 6), and have also encountered v-notched female lobsters for the first time.

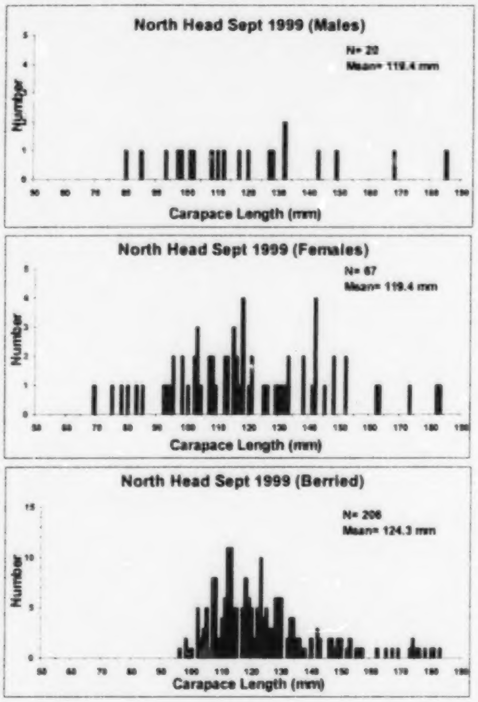

Fig. 6. Lobster size distribution at Flagg Cove.

Future Directions

Under the CLAWS II research program, data from the initial synoptic dive survey conducted in the early 1990's will be geo-referenced using the Geographic Information System approaches adopted in CLAWS I. A subset of the original survey locations will then be reoccupied to provide a decadal-scale comparison of lobster population size frequency and density across a range of benthic habitat types. Additional studies are planned at the two key sites to apply newly-developed research approaches from CLAWS I to these long-term study sites.

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A LOBSTER RECRUITMENT INDEX FROM STANDARD TRAPS (LRIST)

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Project Overview

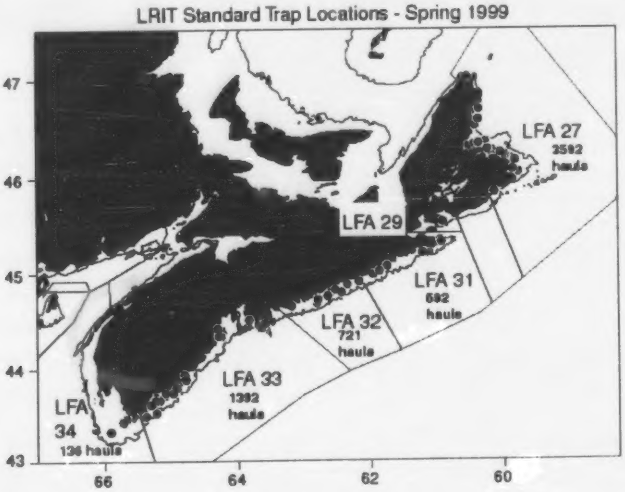
The Lobster Recruitment Index from Standard Traps (LRIST) began in the spring of 1999 with the objective of providing an index of the number of lobsters that will molt into the legal sizes in future seasons. Initiated by the Fishermen and Scientists Research Society (FSRS) in cooperation with the Invertebrate Fisheries Division, the initial phase of the project is planned for five years.

Volunteer fishermen participants track the numbers of lobsters in their catch in standard traps (one inch mesh, wire construction, two compartments, no escape mechanisms). The fishermen sex and count the lobsters in 8 size groups using a specially designed gauge. Size groups (carapace length in mm) are: less than 51 (Size 1); 51–60 (Size 2); 61–70 (Size 3); 71–75 (Size 4); 76–80 (Size 50); 81–90 (Size 6); 91–100 (Size 7) and greater than 100 (Size 8). Size groups 4 and 5 are in 5 mm increments to give a clear indication of the number of lobsters just under the minimum legal size (MLS). In addition, fishermen use their legal gauges to count the numbers of lobsters above and below the MLS in their LFA.

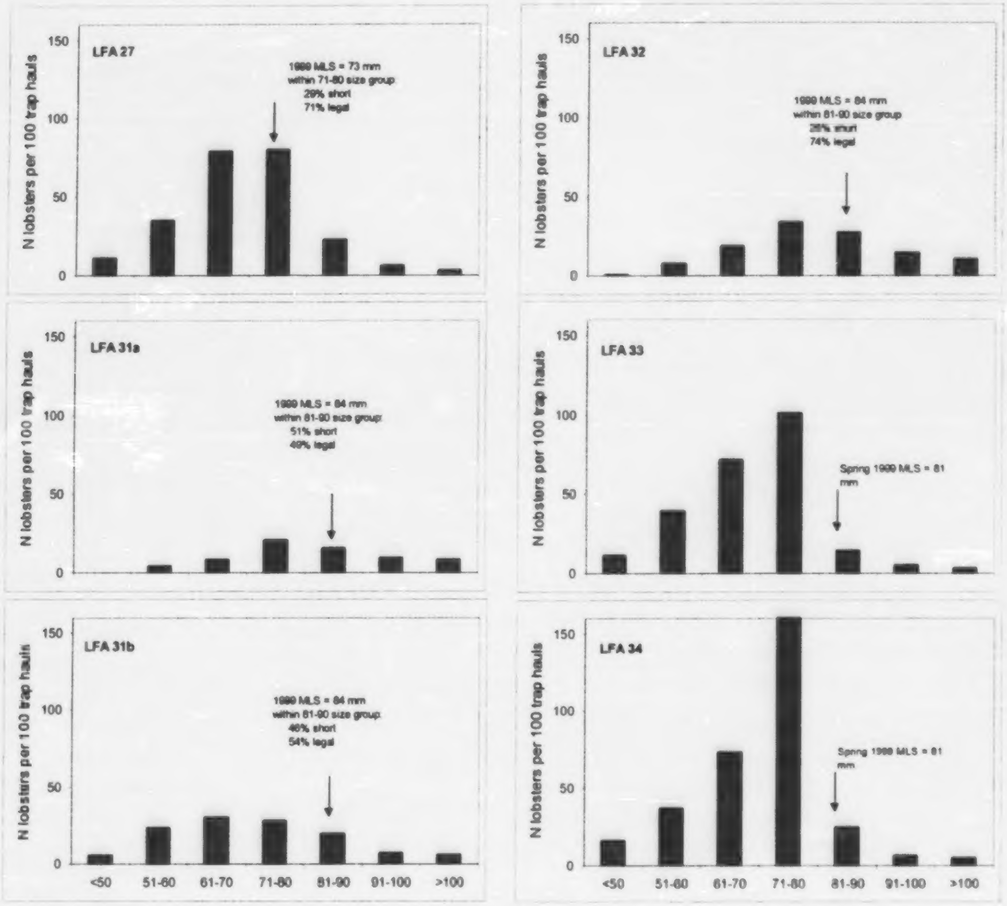
Volunteer fishermen participants also monitor bottom temperatures with a minilog temperature gauge in one of their standard traps.

Results from Spring 1999

A total of 62 fishermen took part in the initial fishing season. They fished the standard traps from the northern tip of Cape Breton to the southern tip of Nova Scotia. Lobster Fishing Areas (LFAs) represented were 27, 29, 31A, 31B, 32, 33, 34.


LRIT Standard Trap Locations - Spring 1999

Each fisherman fished 2-5 standard traps for a total of 193 traps. Over the spring fishing seasons there were a total of 14,078 lobsters counted in 6736 project trap hauls. There were large differences in the catch rate of the different size groups across the LFA's. In general the differences in catch rate reflected the landings in the areas (e.g. higher catch rates in LFA's 27, 33 and 34 where landings are higher).



Future Analyses and Directions

Additional years are needed to determine whether the catch rates of different sized lobsters collected by volunteer fishermen will provide a reliable index of incoming recruits to the lobster fishery. In the meantime, the data collected will be very useful for assessing area and seasonal differences in catch rates, for analyzing the effect of temperature on catch rates, and for identifying hotspots for particular groups of lobsters (e.g. berried lobsters; pre-recruit lobsters). In the future we plan to increase the number of participants in certain LFAs, and possibly to expand to other LFAs.

Acknowledgements

The Fishermen Scientists Research Society thanks all 62 Fishermen who participated in the project in spring 1999, and the community technicians for their work onboard vessels and for working with the fishermen. Richard Nickerson, a fisherman member of the FSRS, first brought forward the idea of an FSRS study of short lobsters. The FSRS gauge was a modified version of one designed by lobster biologists in the Invertebrate Fisheries Division (IFD) (St. Andrews) for use by LFA 35 fishermen.

MATERNAL SIZE INFLUENCE ON LARVAE SIZE AND GROWTH PERFORMANCE IN LOBSTER (*HOMARUS AMERICANUS*)

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American lobsters (*Homarus americanus*) are a highly exploited species in the Magdalen Islands. Recently, improvements in fishing techniques as well as new technologies have increased total landings. An increase of the minimum legal size has been proposed to allow more females to reach sexual maturity before they are captured. However, the exploitation is still focused on small individuals. For the lobster population of the Magdalen Islands as for populations in other regions, the relative contribution of large females to recruitment is not well known. In 1997 and 1998, a research programme was conducted to investigate the relations between female lobster size and characteristics of the larvae.

The objectives were to determine if females of a greater size, relative to females of a smaller size, produce larvae that are larger, develop more rapidly and have a higher survival rate. This study has revealed that the large females' embryos and newly hatched larvae have a higher mean dry weight, a longer mean carapace length and contain more neutral lipids (TAG) than those from small females. Furthermore, the embryos from large females have a proportionally lower water content and therefore, it can be assumed that they contain a greater quantity of energetic elements required for their development.

Moreover, in the experiments of 1997, the larvae from large females maintained a higher growth rate and developed faster than larvae from smaller females. However in 1998, changes in rearing conditions seem to have had a negative effect on larval development. The results on growth performance have also shown the possibility for larvae from small females under a high food ration to reach the size of larvae from large females under a small food ration. However, larvae from small females never become larger than larvae from large females.

Although these results represent only a small proportion of the population, they suggest that large female lobster could have a significant impact on the success of recruitment to the population.

PUTTING LOBSTERS ON THE MAP: LOBSTER HABITAT RESEARCH IN THE CLAWS FISHERIES ECOLOGY PROGRAM

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In this poster we describe our research approaches for studying the spatial structure of coastal habitats for a range of scales from centimetres to kilometres using sidescan sonar, remote and diver-deployed video imaging, and physical sampling methods in two geologically different regions in eastern Canada. Differential GPS was used to geo-reference all sampled substrates and benthic organisms from video transect and quadrat data. These data were mapped onto sidescan sonar mosaics using a Geographic Information System (GIS) and are readily accessible in a relational database.

The St. Andrews team has been working with scientists at BIO, Gulf Fisheries Centre in Moncton, the New Brunswick Department of Fisheries and Aquaculture, the Maritime Fishermen's Union and Nova Scotia fishermen to examine the benthic habitat in two prime fishing areas. Val Comeau in the southern Gulf of St. Lawrence and Lobster Bay off Southwest Nova Scotia, are well known for their lobster fishery productivity. The two areas were first mapped by the Geological Survey of Canada. They produced high-resolution side-scan sonar maps of the seabed – 12 km^2 of Lobster Bay and a 7 km^2 area for Val Comeau. Next, the maps were "groundtruthed" by biologists and geologists based on remote and diver-held video surveys.

We describe our sampling methods which in Val Comeau consisted of approximately 26 km of remote camera survey tracks, over 9000 m^2 of diver-held video images, and over 3000 quadrats (total area = 750 m^2) on 100 m transects that were measured and searched. In addition to transect surveys, high resolution imaging and sampling of quadrats, nested in groups of 25 (area = 6.35 m^2) or 100 quadrats (area = 25 m^2), were also completed. In Lobster Bay, approximately 12 km of remote camera and over 2000 m^2 of diver-held video images were taken and 400 quadrats (0.25m^2) were physically measured and searched.

The main focus of this research was on how American lobster (*Homarus americanus*) distribution patterns are affected by the spatial arrangement and scaling of habitat patches within major production areas. The goals are to relate size and density of juvenile lobsters to specific habitat characteristics, including the size and arrangement of different seabed types and to link the distributions of juveniles, which are often restricted to particular habitats, to fishery size lobsters which can range over several kilometres, and cross a number of habitat types. An additional challenge is to develop these research approaches to the point where information from regional-scale seabed mapping can be used to predict where sensitive lobster habitats may be located throughout the Maritimes.

STREAMER TAG LOSS FROM AMERICAN LOBSTERS

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Abstract*

Polyethylene Streamer Tags are used on American lobsters (*Homarus americanus*) yet there has been no attempt to investigate sources of variability of tag loss. Using a secondary mark, I estimated that Streamer Tag loss after about eight months was 17.8% and after one year was 18.1%. After one year, I observed 40.0% tag loss for lobsters that had molted and 11.1% for lobsters that had not molted. I found no difference in Streamer Tag loss in relation to lobster sex or size. The results showed that tag loss can be substantial and therefore, the possibility that tag loss may introduce serious bias should be considered for any estimates of population characteristics based on Streamer-Tagged animals.

*Full paper accepted for publication in Transactions of the American Fisheries Society

FUTURE FUNDING FOR CANADIAN LOBSTER RESEARCH: CLAWS II

Michael Chadwick

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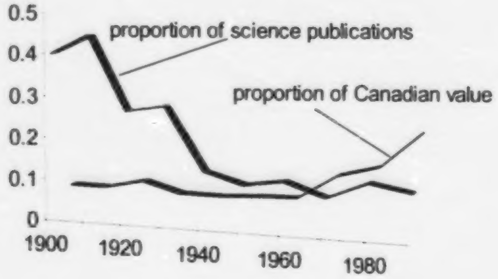
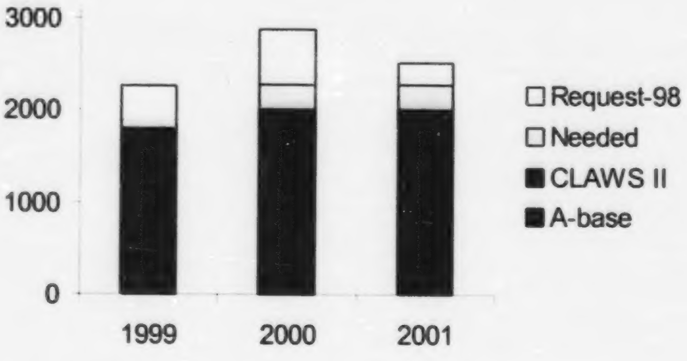
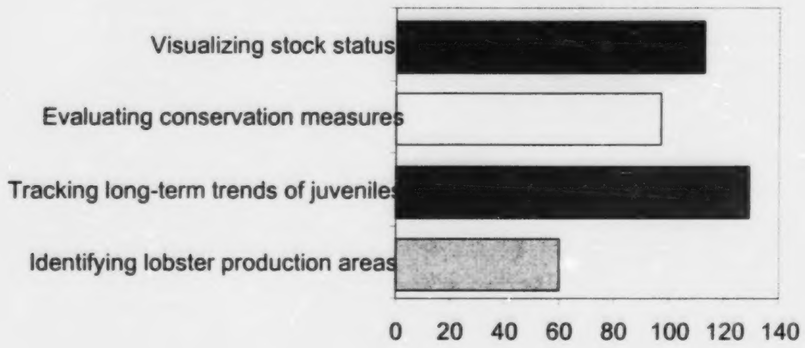
This session examined the next phase of the lobster research funding. The objectives of phase two remain the same as in phase one. Namely, continue the research initiated in 1996 to improve our understanding of stock status, our ability to assess new conservation measures, our understanding of long-term trends and the scientific framework for management of lobster. One important reason for this continued funding is that the lobster resource continues to grow in value, today worth about 25% the value of all Canadian aquatic resources. Throughout the past century there has been a decline in the proportion of research dedicated to lobster as seen in the figure below. The CLAWS funding is intended to help rebuild an interest in lobster science that is more proportional to the value of lobster to the economy.



It can be seen in the following figure that CLAWS funding helps to increase science budgets by about 20%. See the grey and black blocks in the graph below. Nevertheless, the new funding is less than half of the money required to make significant improvements to our research needs. Compare the grey and white blocks in the figure below. We are hoping that industry will be able to contribute some funding to this type of research.



CLAWS II is divided into four themes as shown in the following graph. Visualizing stock status (black bar) includes support for fishery-independent surveys in Northumberland Strait and Magdalen Islands, habitat mapping, work on improving estimates of exploitation rate, catchability, fishing effort and stock assessments. Evaluating conservation measures (white bar) includes work on the importance of adult size in the survival of lobster offspring and also work on growth of large lobsters and evaluating the effectiveness of closed areas as a conservation measure. The major thrust of funding will be towards tracking long-term trends in recruitment (dark grey bar), mainly by developing in-site indices of juvenile abundance in Magdalen Islands, Northumberland Strait, and Gulf of Maine. The last thrust (light grey bar) will be to improve our understanding of lobster production areas as defined by the FRCC 1995 report. This work will be focussed on better estimates of larval drift, analysis of environmental factors and a better understanding of geographic variation in the abundance of stages 1 and IV larvae.



DISCUSSION NOTES FROM THE CLAWS SYMPOSIUM

Howard Powles

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Over the two day scientific session and one day industry session a number of issues were raised during the course of discussions. The following is an attempt to capture some of the key points relating to each of the five session topics plus general comments.

General

- Lobsters are important to the Atlantic fishery, generating wealth and employment.
- Continued scientific research is required to understand the biology of lobster. With better knowledge there can be better advice for the management of lobster stocks.
- Some industry observers argued that no changes to management should be made until science can provide answers to all questions about lobster populations. Others argued that enough is known and that conservation measures must be taken.
- Collaborative efforts involving stakeholders, universities and both federal and provincial governments is positive and helps generate the resources required for research.
- Based on the value of the fishery government should put more resources into lobster research.
- We need to be proactive in generating information on fish stocks and not operate on a crisis basis.
- By involving fishermen in projects, they can appreciate how science is conducted. This reduces the fear of Science.
- There must be effective communication between scientists and fishermen.

Session 1- Larval Drift

- Models of larval drift will be realistic after the integration of larval behavior with the physical current models. The models also need to be able to assess the effects of catastrophic events such as storms. Some fishermen noted that the movement of lost gear suggested greater current movement than the model.
- Where do lobsters recruit from? Areas such as Lobster Bay produce large numbers of Stage 1 larvae and has a large adult population but Stage IV larvae are not found. If the recruits come from other areas they need to be identified so they can be properly protected.
- What is the impact of predation on larvae?
- Is there a critical stage that determines recruitment?
- As berried females do not trap well, how can we get reliable estimates of egg production?

Session 2 - Juvenile Lobster

- Fishermen from the Gulf of Maine area generally disagreed with the conclusion that groundfish do not eat lobsters. They stated that they have seen groundfish such as cod, cusk and wolffish with lobsters in their stomachs. The paper reporting no lobsters in the stomachs of groundfish was based on a study in the Southern Gulf, where lobsters and groundfish generally do not co-occur.
- There is a need to look at the relationship between the number of pre-recruits and the subsequent number of recruits. The development of a recruitment index would be useful.
- Smaller rock crab are an important food item for lobsters, particularly for larger lobster. The quantity of crab required to feed lobster should be determined and taken into account in the management of the rock crab fishery.
- The interaction between small and large lobsters should be examined in relation to distribution, territoriality, mortality (large lobsters can kill small lobster).
- Fishers noted that they are seeing more berried females, seeing lobsters in areas where they were not previously seen and seeing 1-2 inch lobsters. Rationales are needed to explain differences between the current situation and the past.

Session 3 – Catchability

- The catch composition (size and number) must be related to the abundance and size composition of the population. This can be done on a small scale with controlled diving and trapping studies to measure the effects of different factors (e.g. trap type, bait, season, habitat) on catch rate.
- Trap size, ring size and bait vary among ports, and seasons and have changed over time. These factors will affect catchability and need to be evaluated.
- How can effort be measured to reflect the changes made to gear by fishermen and the expansion of fishing grounds.
- Need a selective trap that does not retain small lobsters and excludes large lobsters.

Session 4 – Assessment Parameters

- Do we really know where we are in relation to stock abundance? In some areas catches are increasing while in others catches are declining.
- Biological reference points must be practical and clearly stated.
- Fishermen need to understand the biological information and the logic behind conservation measures if they are to support them.

Session 5 – Fishermen and Science

- "Snow crabs are like dogs; lobsters are like cats."

- Lobsters are fished over a wide area. How applicable are the results from a study conducted in one area to other areas? Do lobster stocks in areas of low productivity react the same as stocks in areas of high productivity?
- The co-operation of fishermen in collecting/providing data is required if we are to have coverage of a broad area.
- Need to work together to get the resources to conduct research. Have to get resources from a variety of sources. Fishermen organisations can sponsor projects.
- Need to involve fishermen in projects and utilise the knowledge they have gained through years of fishing.

CLAWS II

- It is a continuation of and builds on CLAWS I
- Projects are distributed throughout the Atlantic, however, fishermen would like to see more areas included in each study. Would like to see both good and poor production areas included.
- Studies should continue over a long enough time to cover periods of both good and poor environmental conditions.
- Annual migration patterns should be determined.

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